Speeding Up Linux Disk Encryption

Ignat Korchagin
@ignatkn

$ whoami

- Performance and security at Cloudflare
- Passionate about security and crypto
- Enjoy low level programming

Encrypting data at rest

The storage stack

applications

The storage stack

applications

filesystems

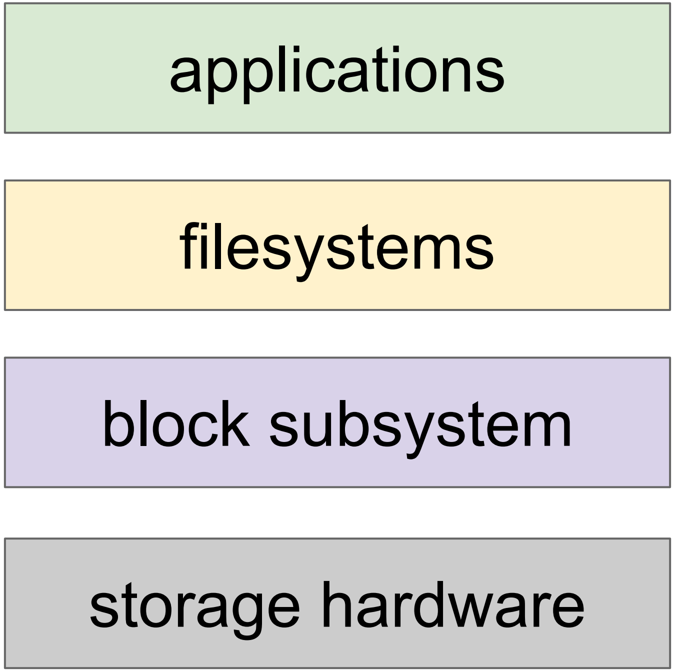
The storage stack

applications

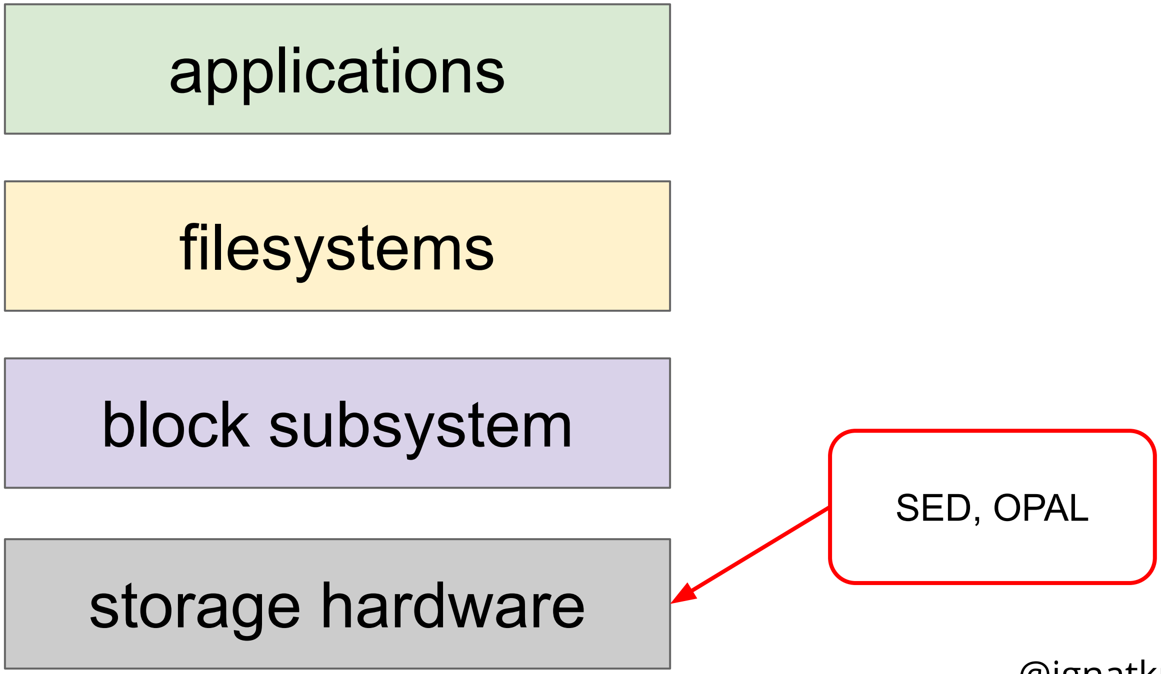
filesystems

block subsystem

The storage stack



Encryption at rest layers



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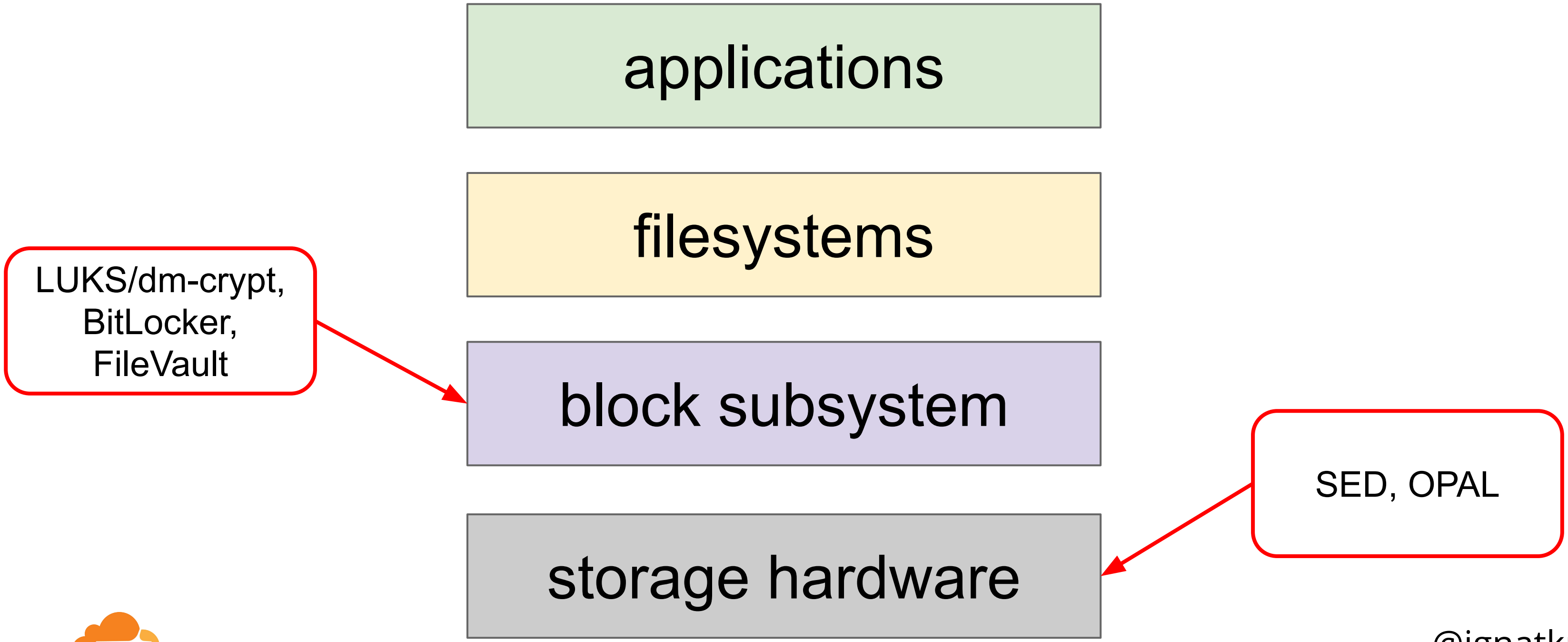

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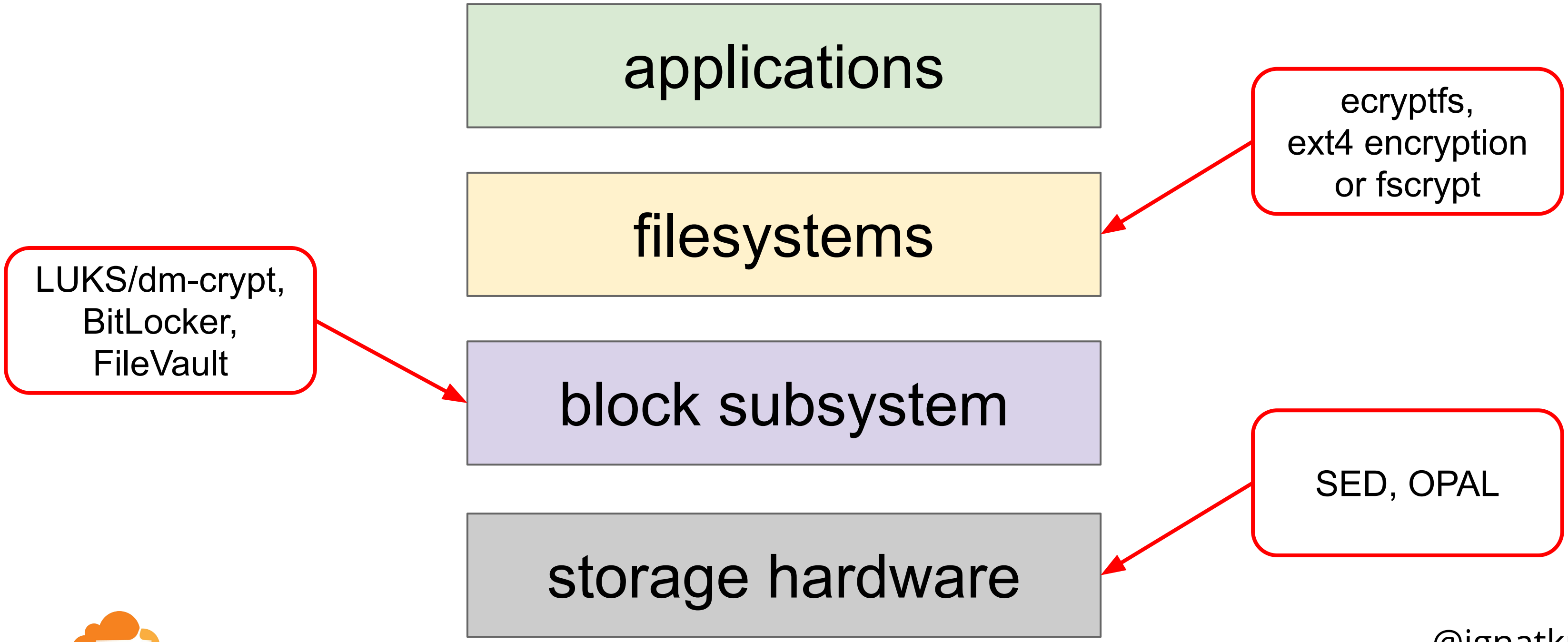

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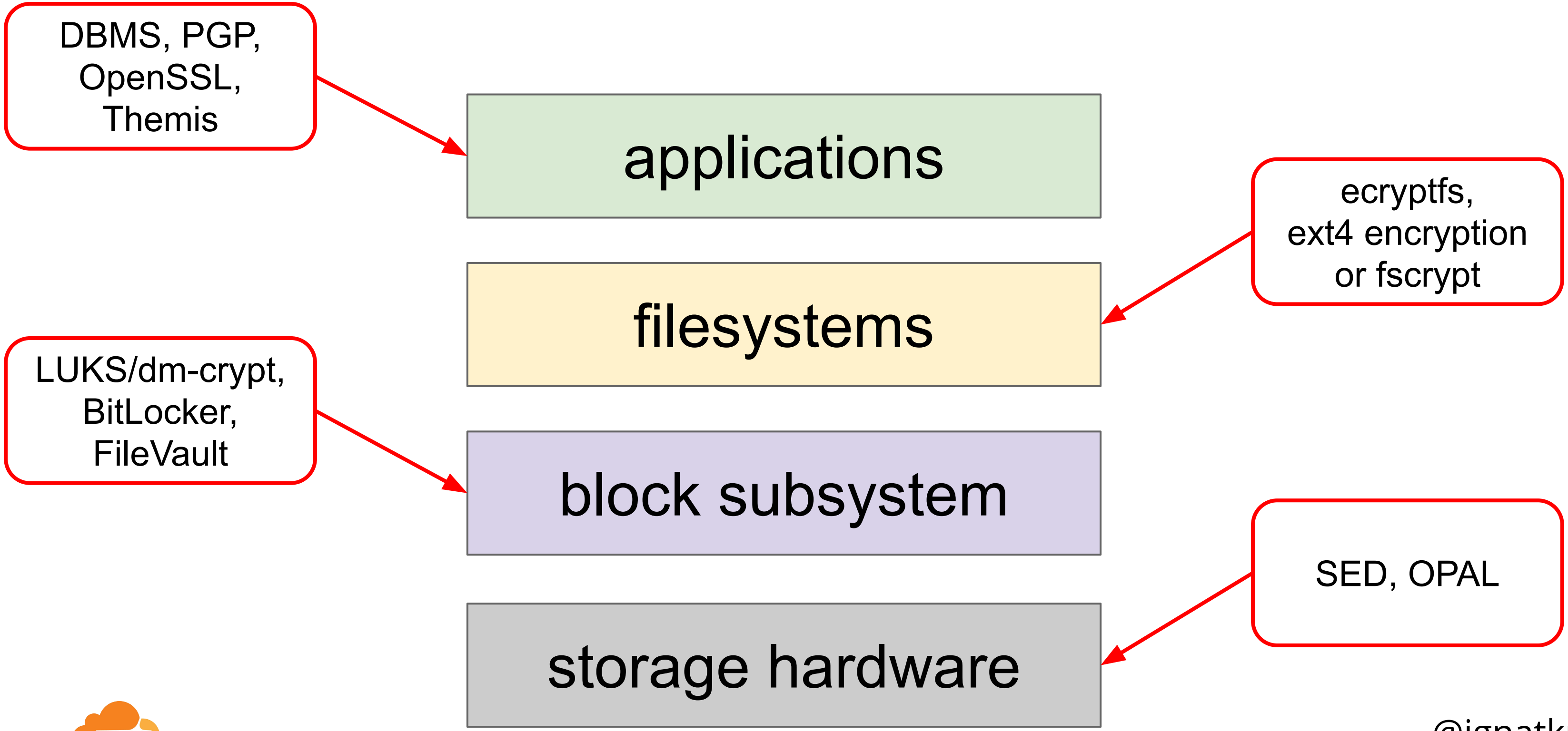

Storage hardware encryption

Pros:

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Cons:

- no visibility into the implementation
- no auditability
- sometimes poor security

https://support.microsoft.com/en-us/help/4516071/windows-10-update-kb4516071

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LUKS/dm-crypt

Device mapper in Linux

applications

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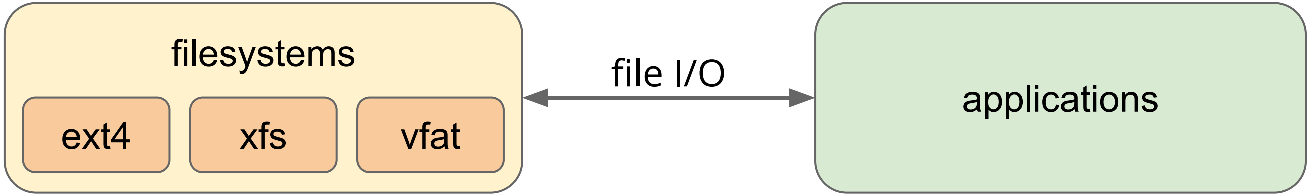

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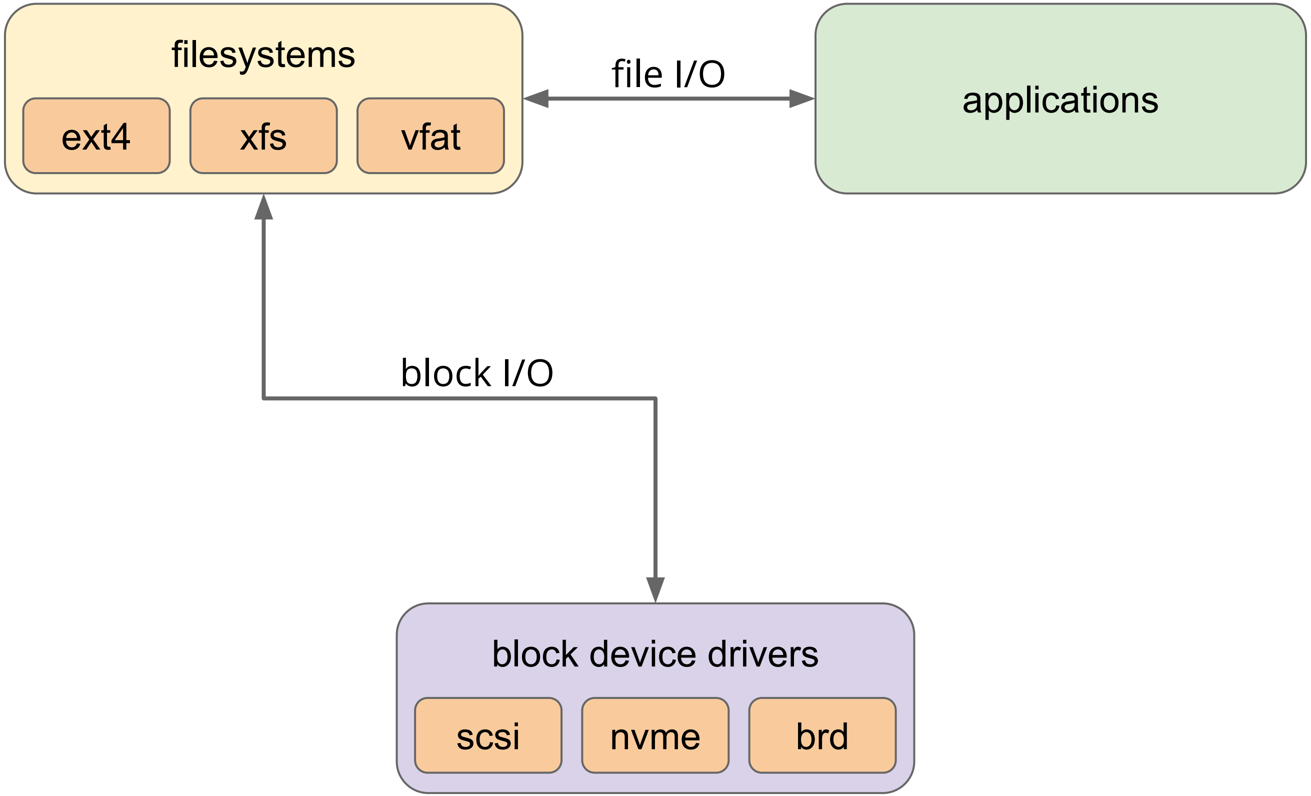

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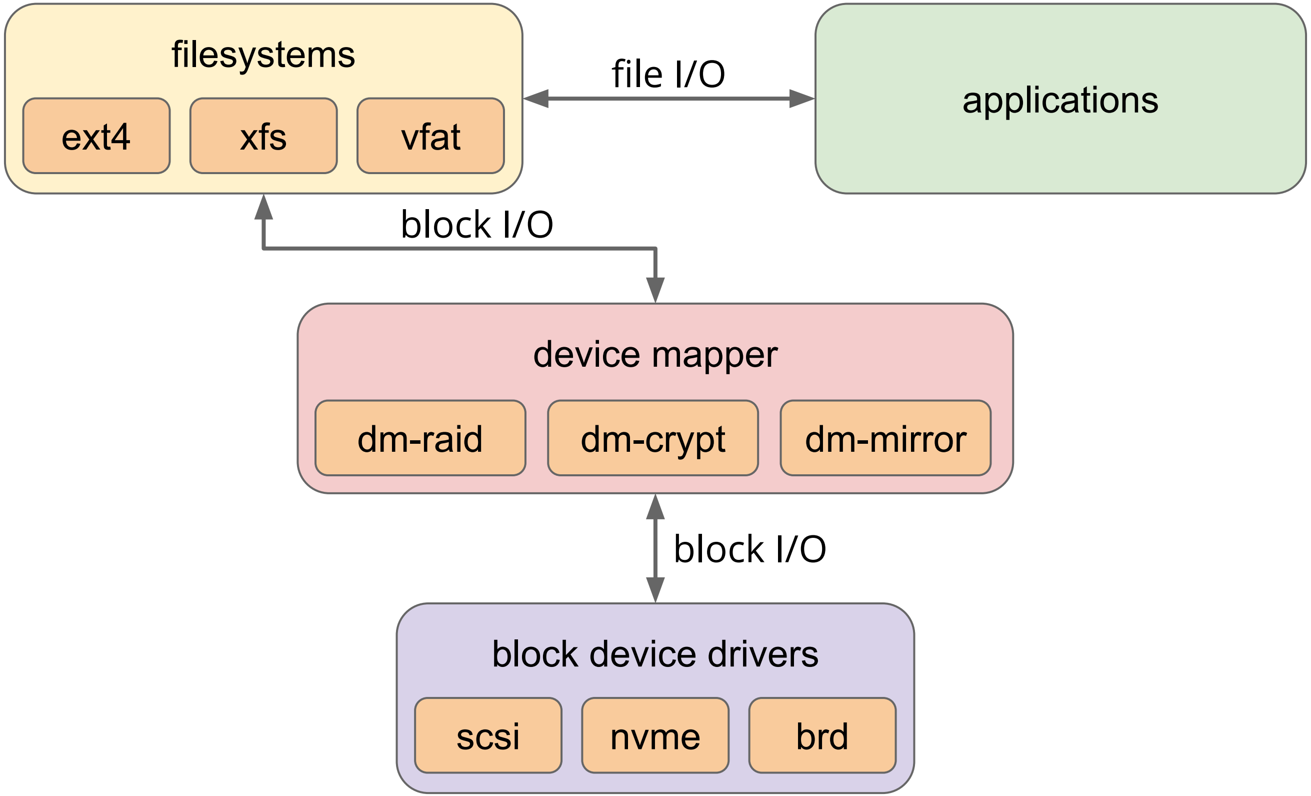

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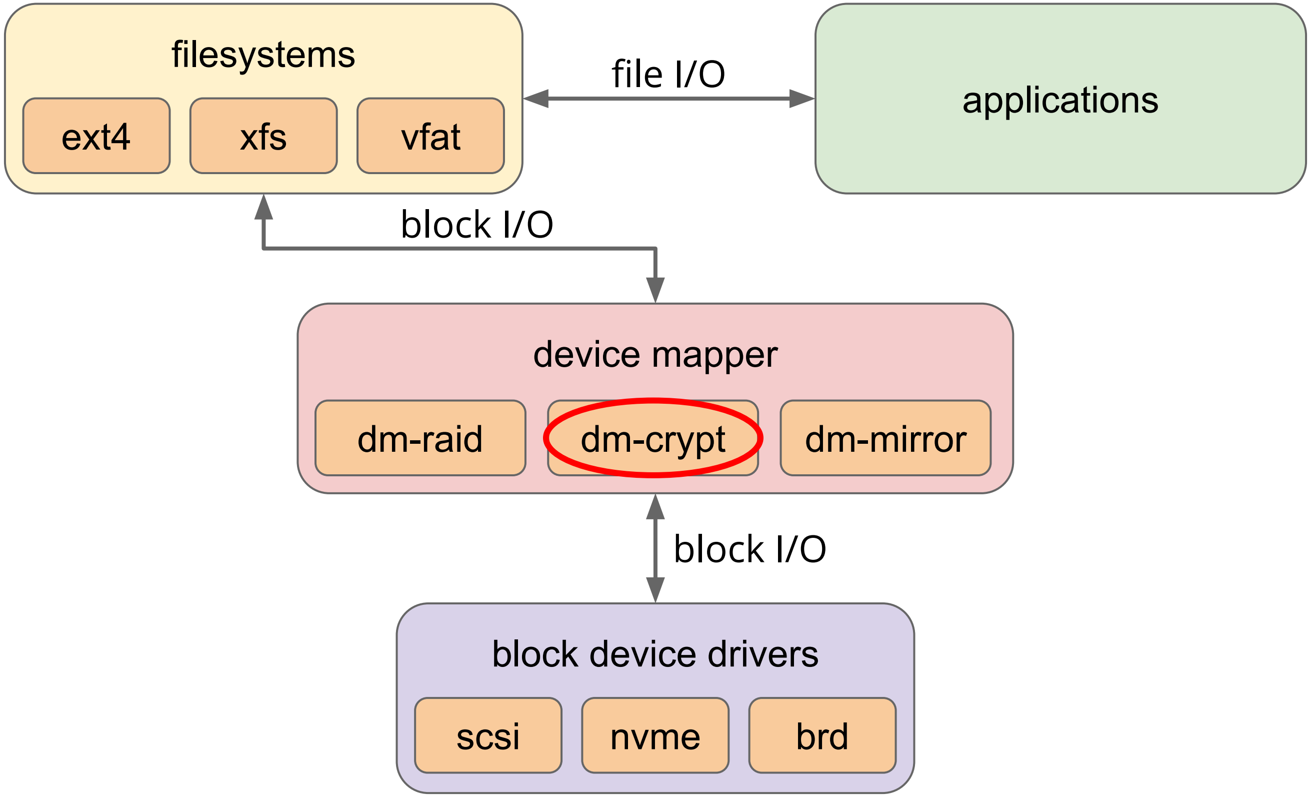

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dm-crypt (idealized)

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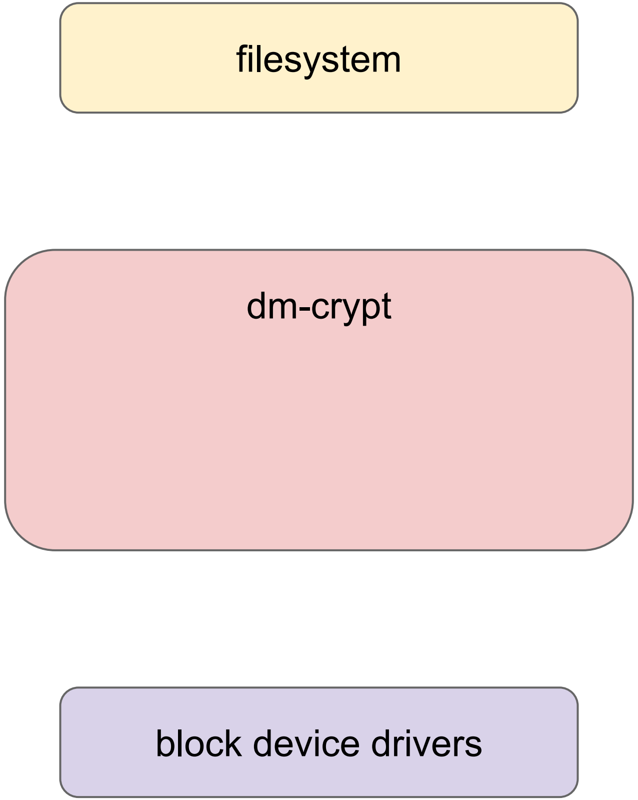

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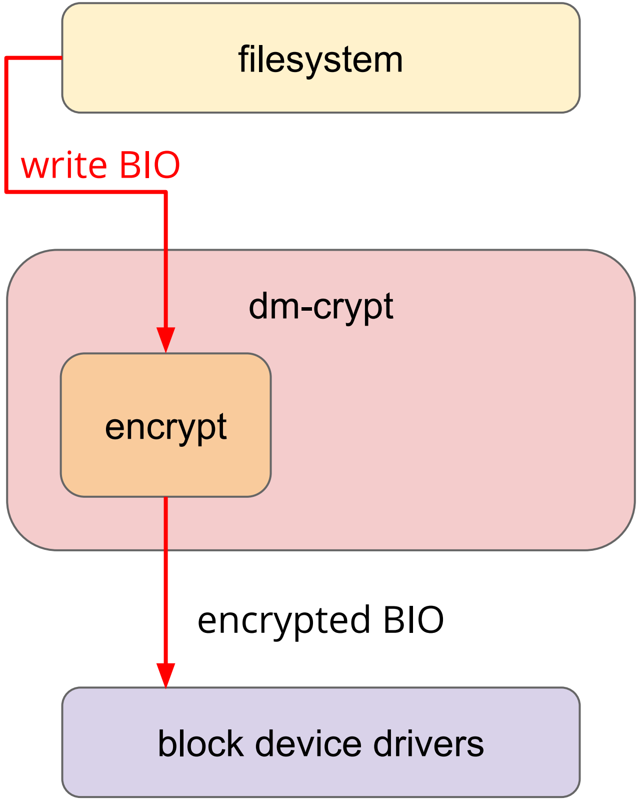

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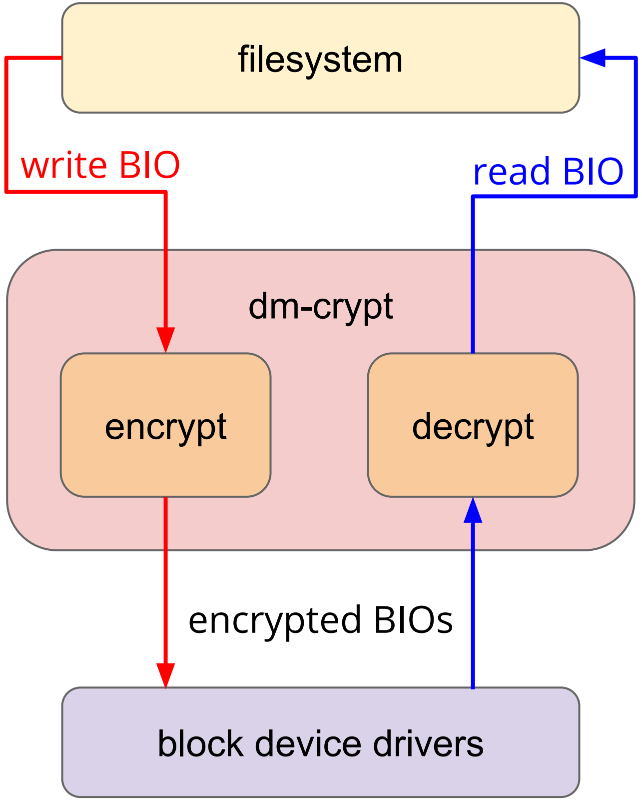

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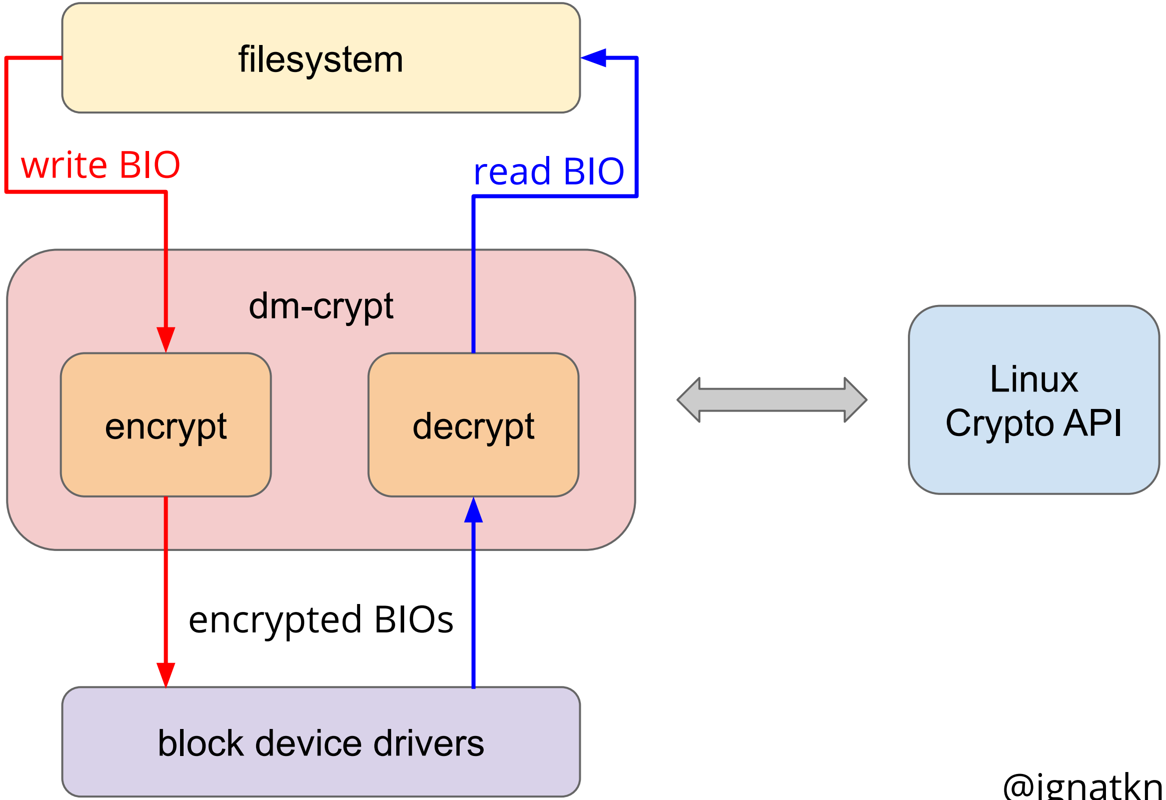

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dm-crypt benchmarking

Test setup: RAM-based encrypted disk

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$ sudo cryptsetup open --type luks
/dev/mapper/plain secure
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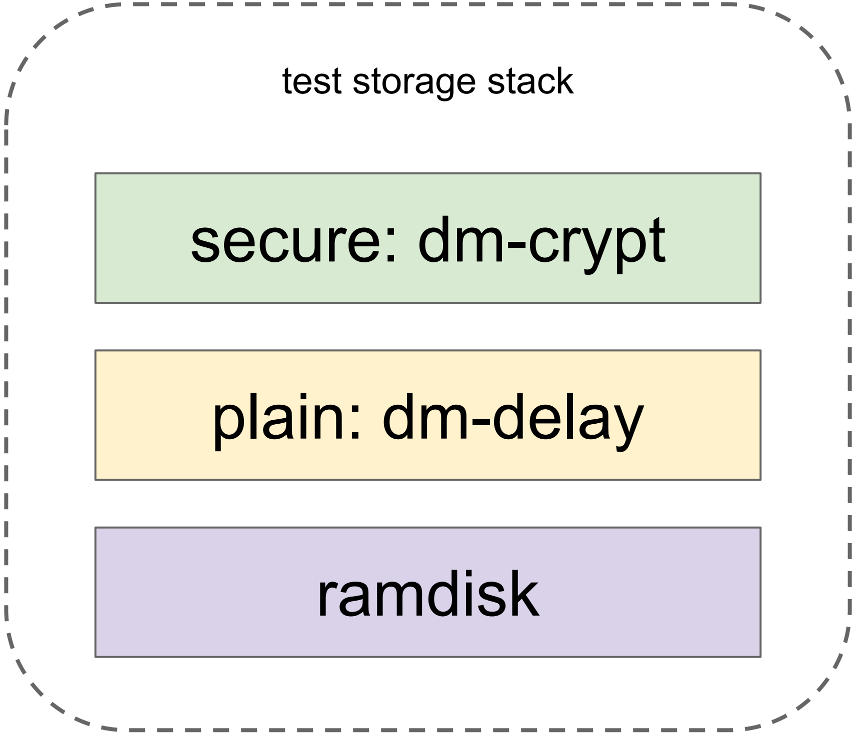
Test storage stack



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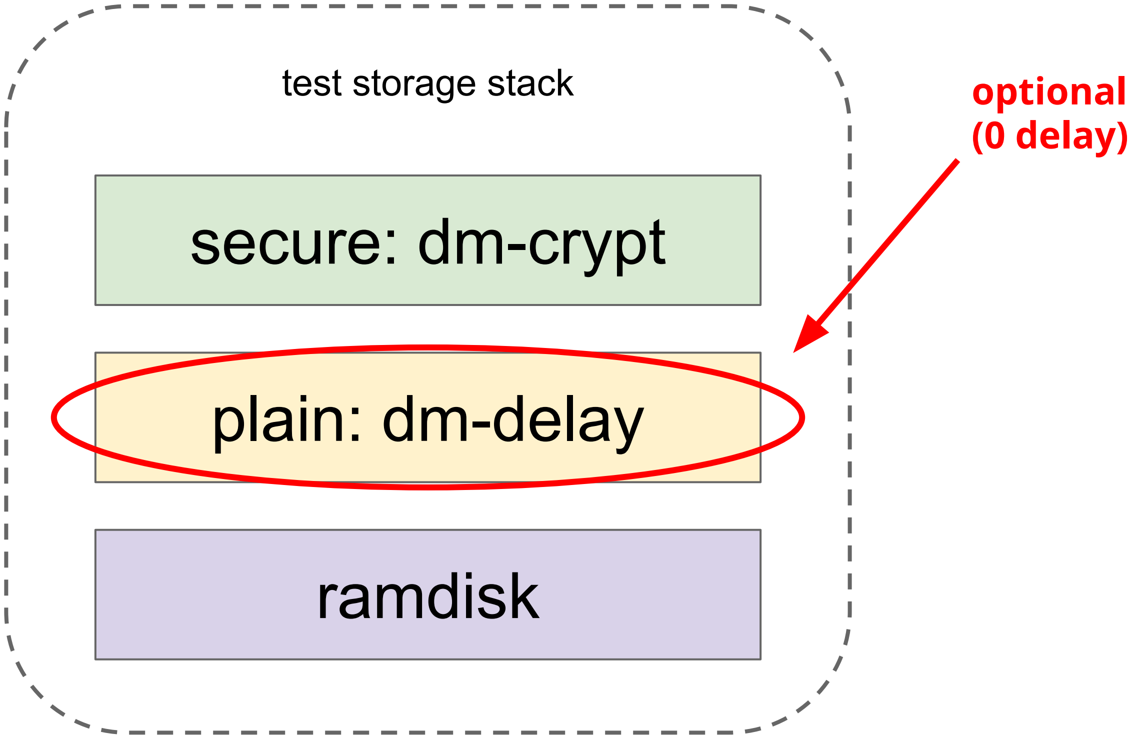

Test setup: sequential reads

```
$ cat rw.job
[iotest]
direct=1
gtod_reduce=1
loops=1000000
iodepth=16
```

Test setup: sequential reads

```
$ sudo fio --filename=/dev/mapper/plain
--readwrite=read --bs=4k rw.job
...
   READ: io=21134MB, aggrb=1876.1MB/s
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--readwrite=read --bs=4k rw.job

...
   READ: io=3261.8MB, aggrb=318.6MB/s
```

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Test setup: sequential reads

```
$ sudo cryptsetup benchmark -c aes-xts
# Tests are approximate using memory only (no
storage IO).
#  Algorithm | Key |  Encryption |  Decryption
     aes-xts   256b  1854.7 MiB/s  1904.5 MiB/s
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desired: **~900 MB/s**, actual: **~300 MB/s**

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- experimenting with dm-crypt optional flags
  - “`same_cpu_crypt`” and “`submit_from_crypt_cpus`”

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  - aes-xts seems to be the fastest (at least on x86)
- experimenting with dm-crypt optional flags
  - "`same_cpu_crypt`" and "`submit_from_crypt_cpus`"
- trying filesystem-level encryption
  - much slower and potentially less secure

Despair

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Ask the community

“If the numbers disturb you, then this is from lack of understanding on your side. You are probably unaware that encryption is a heavy-weight operation...“

https://www.spinics.net/lists/dm-crypt/msg07516.html

But actually…

"Using TLS is very cheap, even at the scale of Cloudflare. Modern crypto is very fast, with AES-GCM and P256 being great examples."

https://blog.cloudflare.com/how-expensive-is-crypto-anyway/

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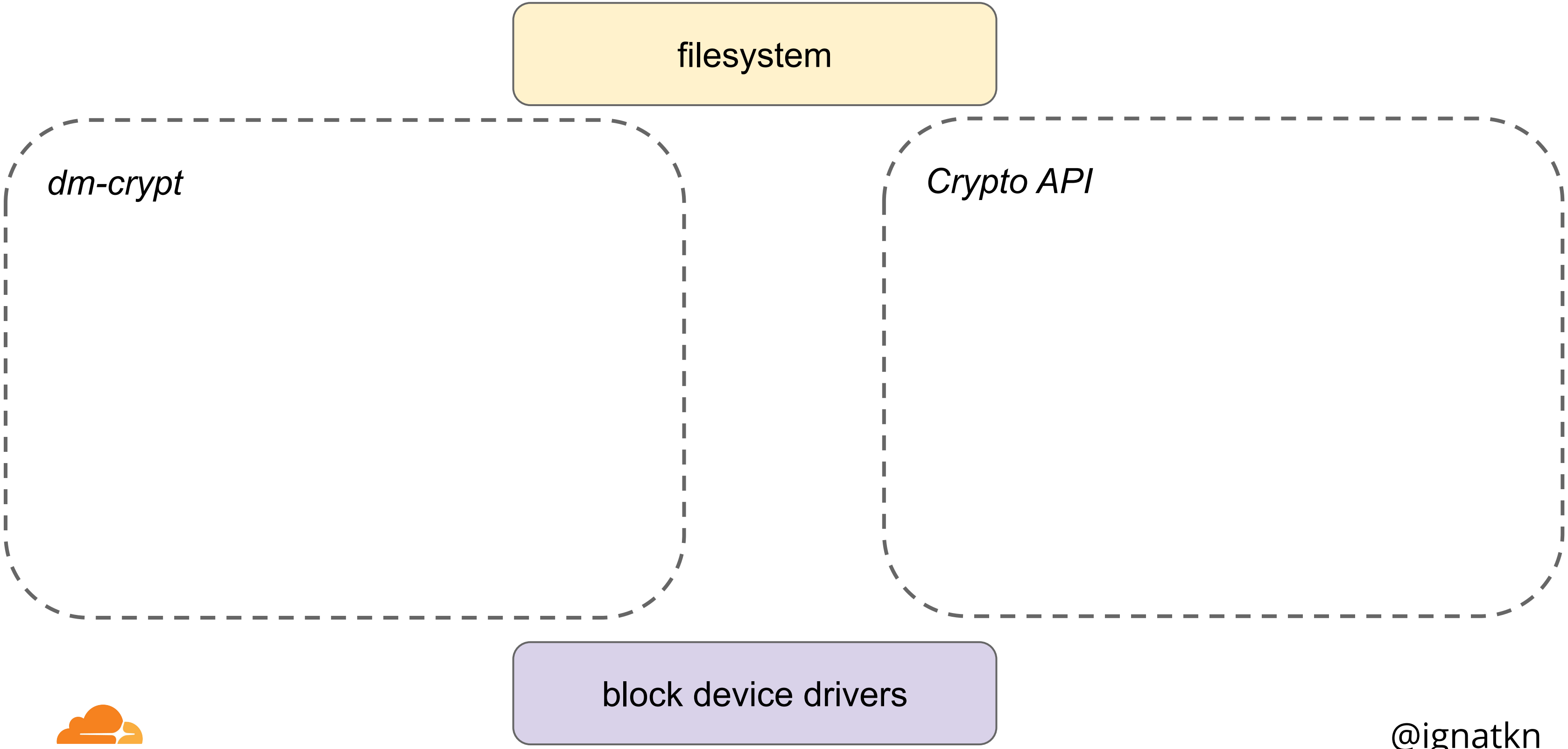

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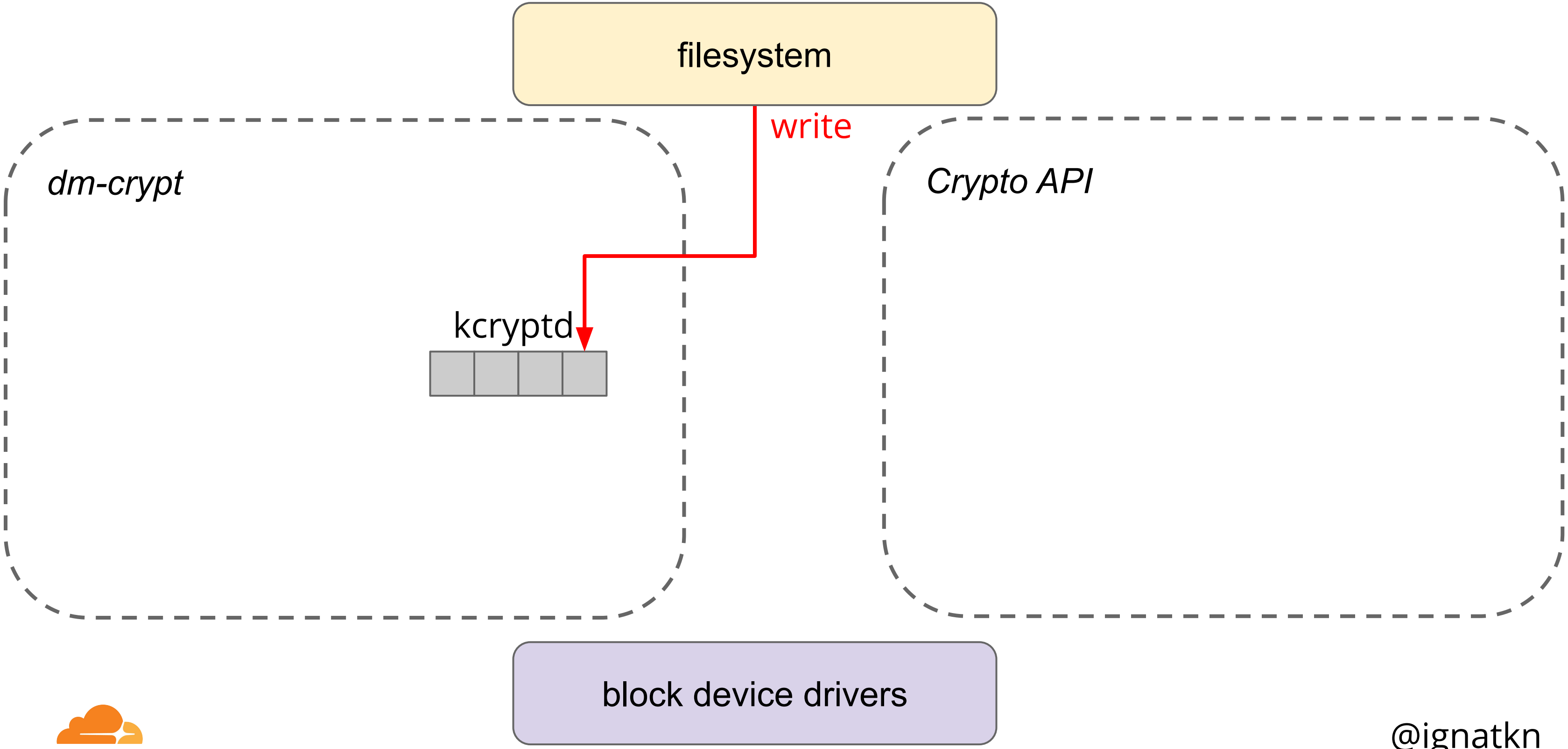

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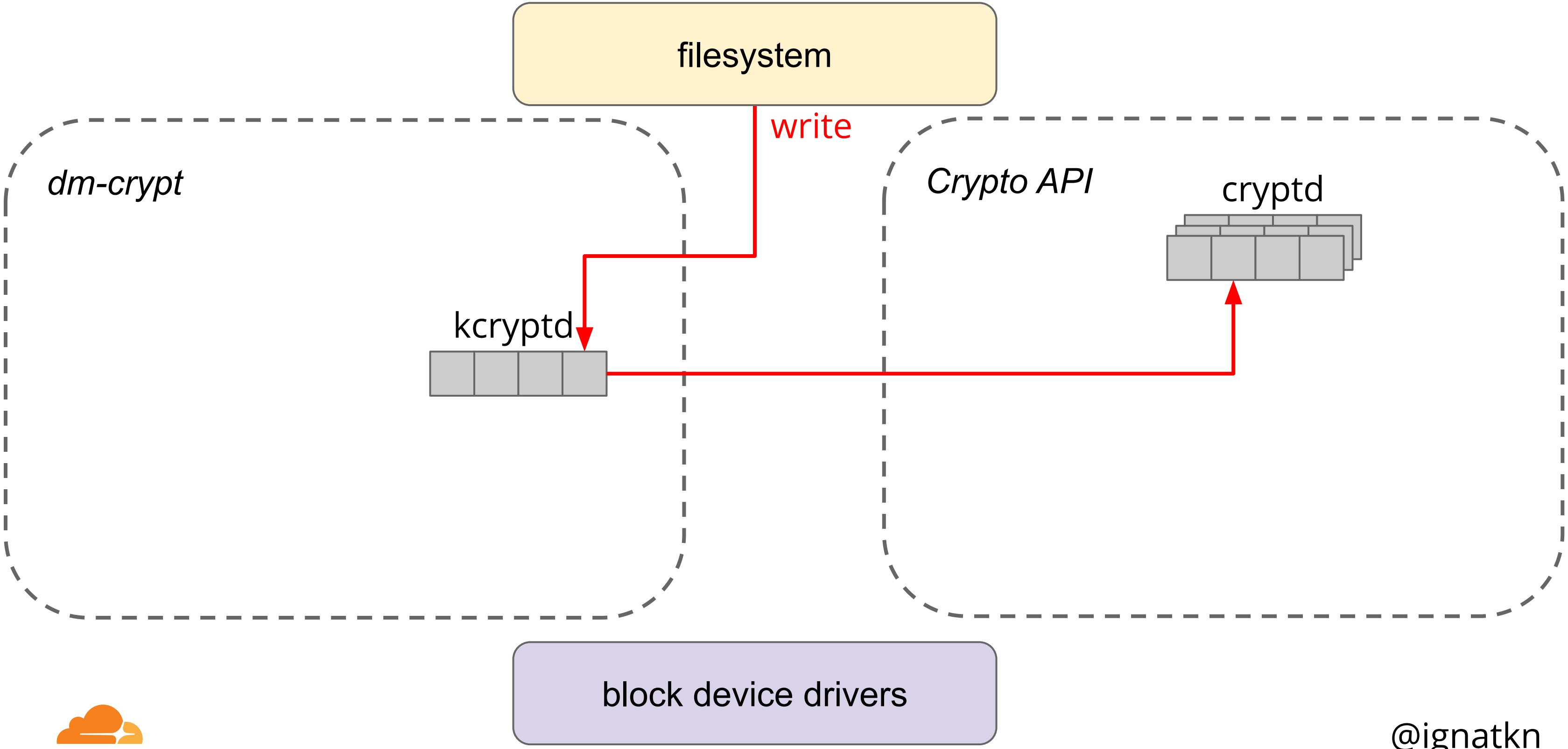

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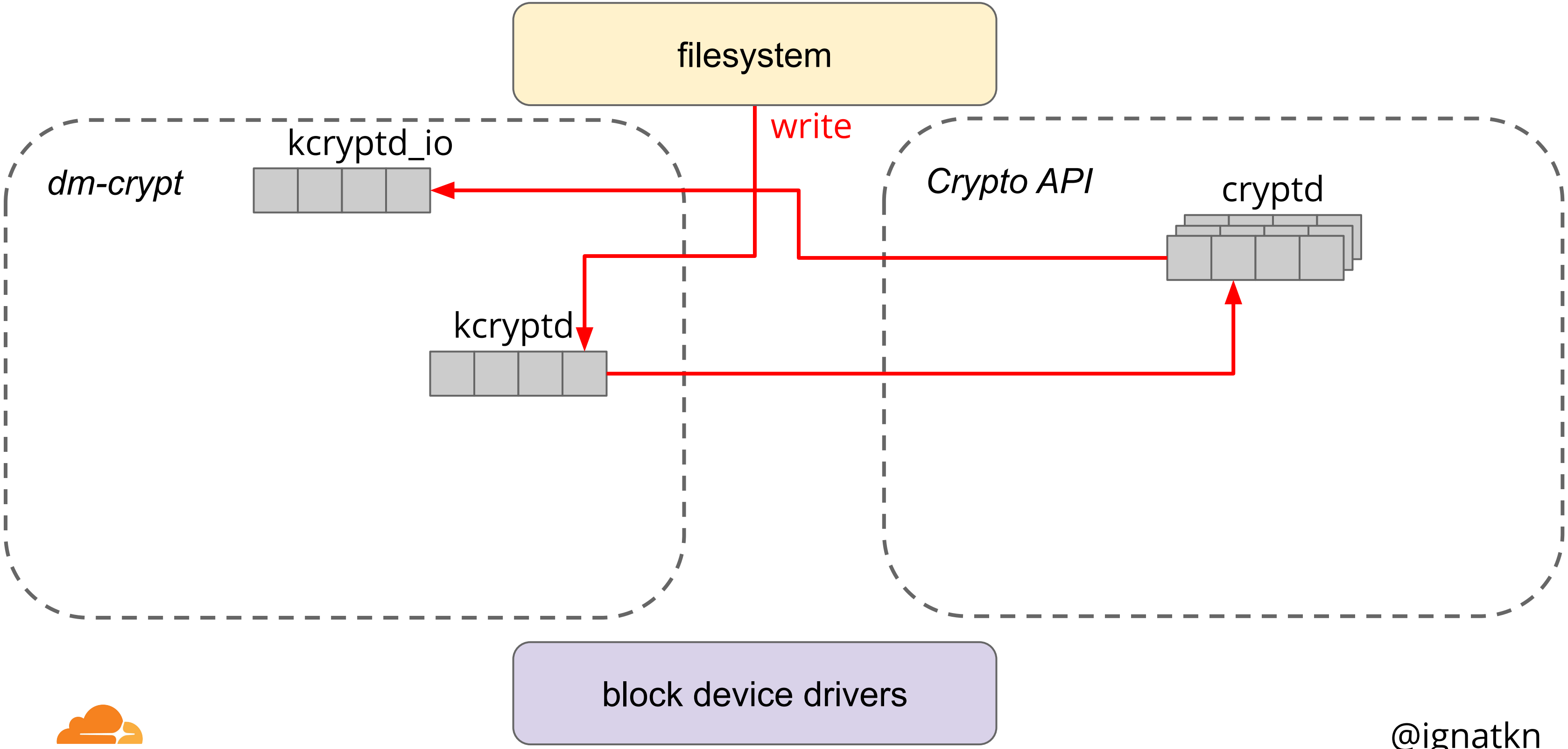

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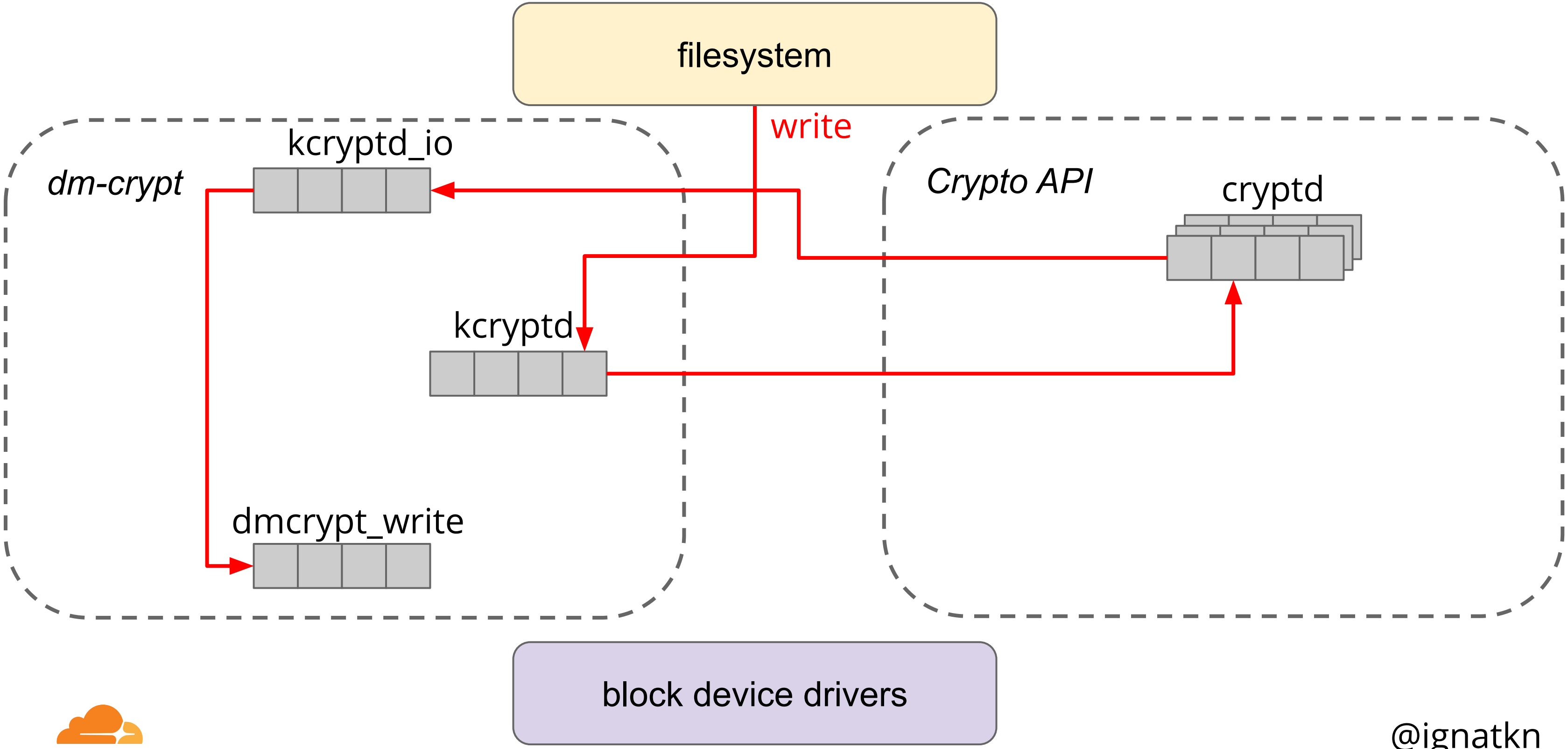

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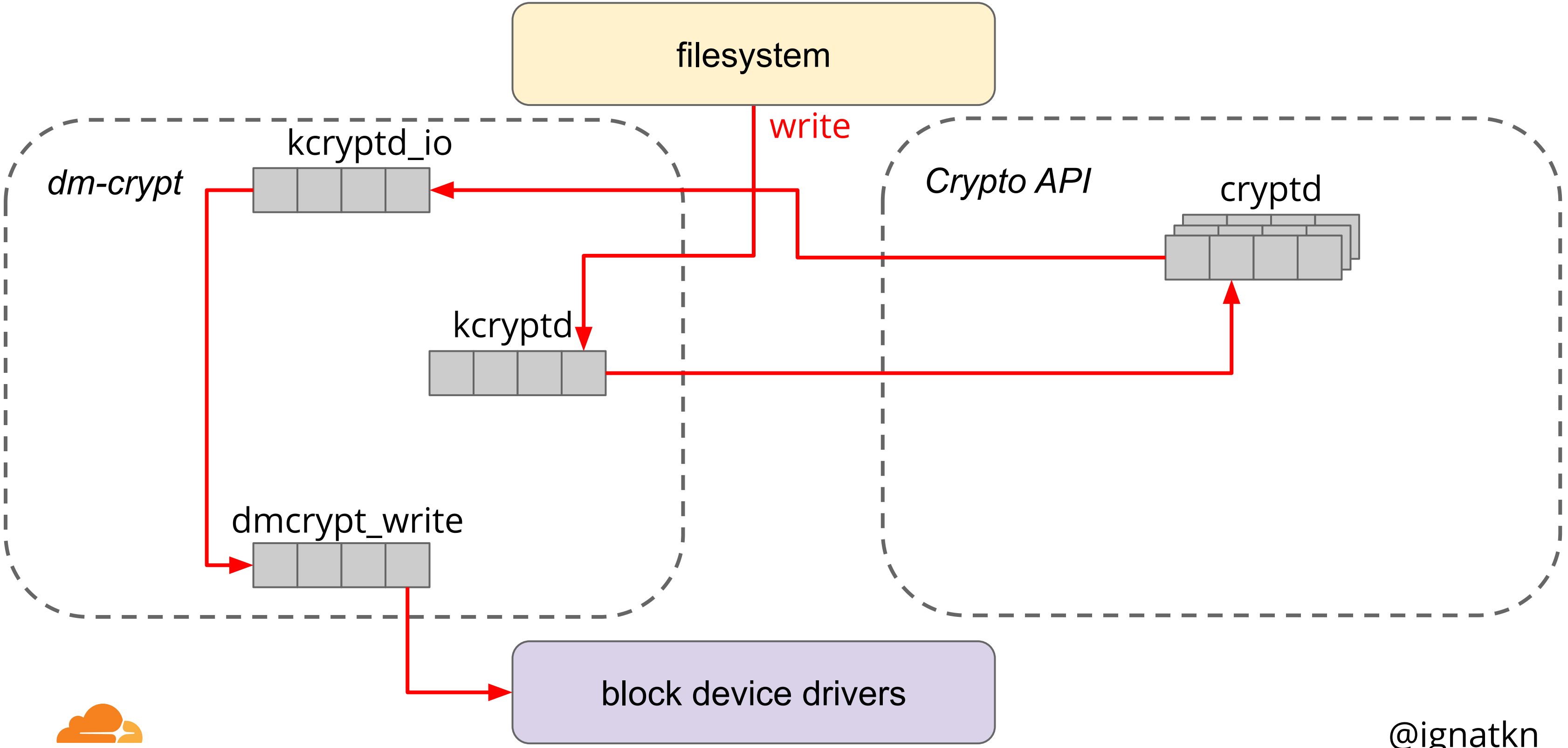

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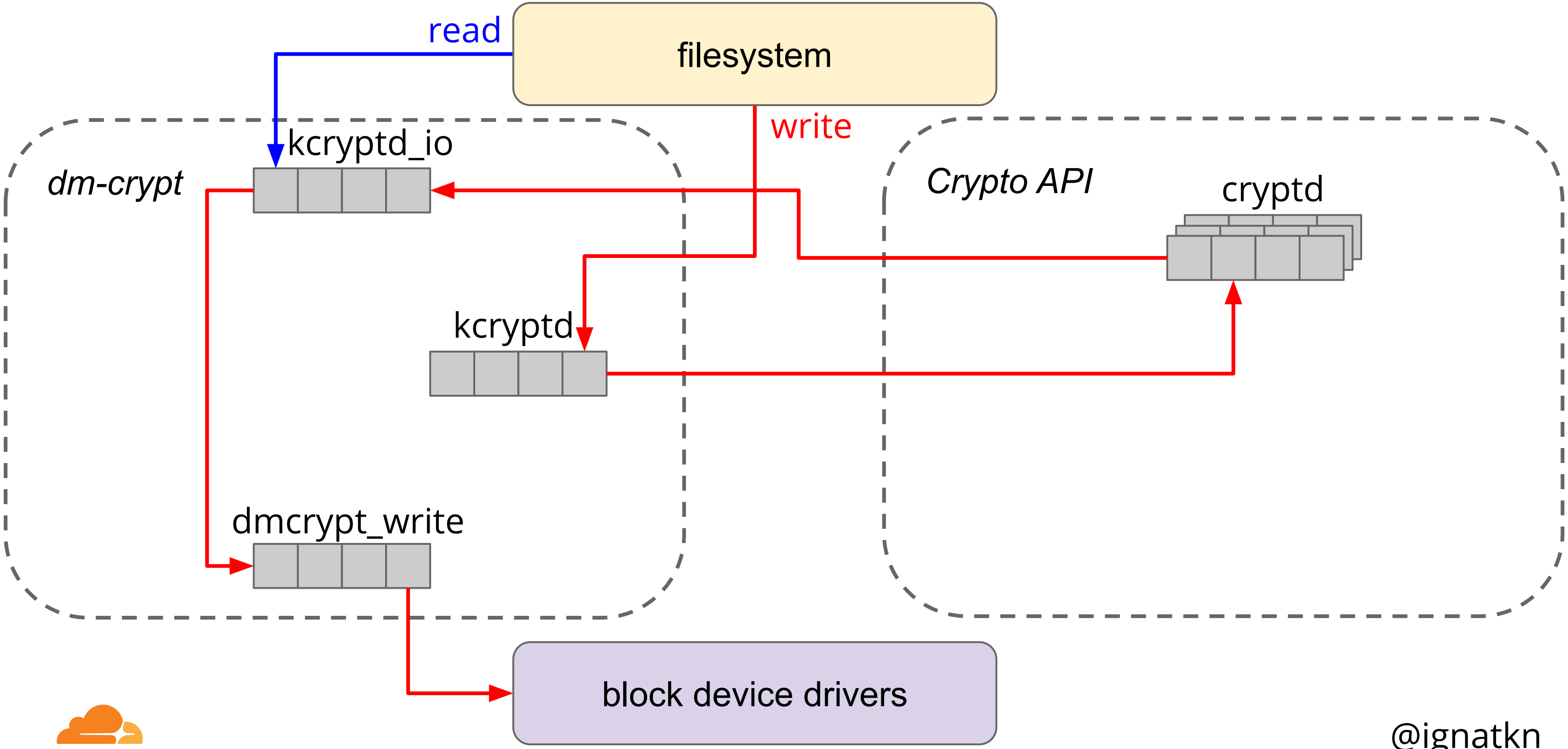

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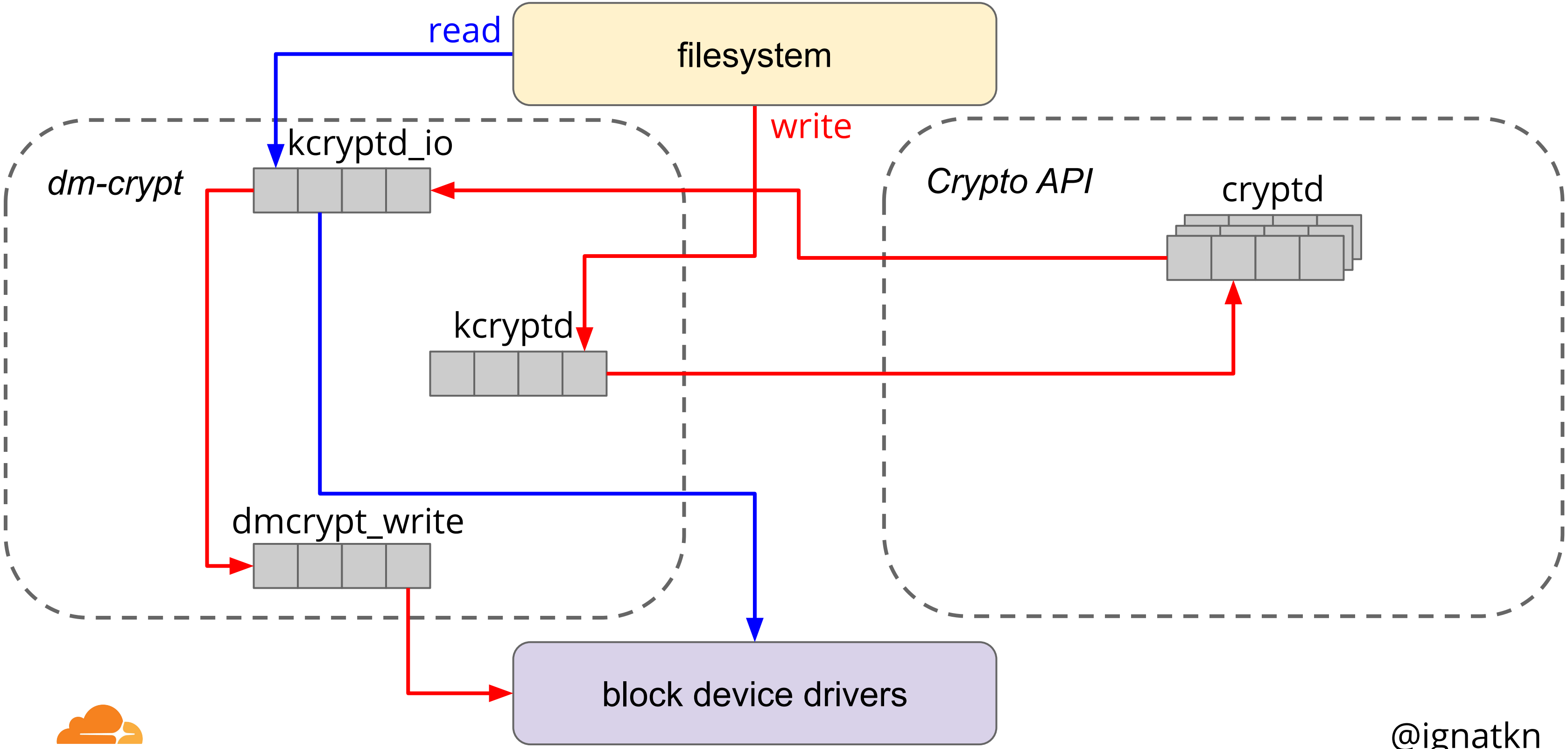

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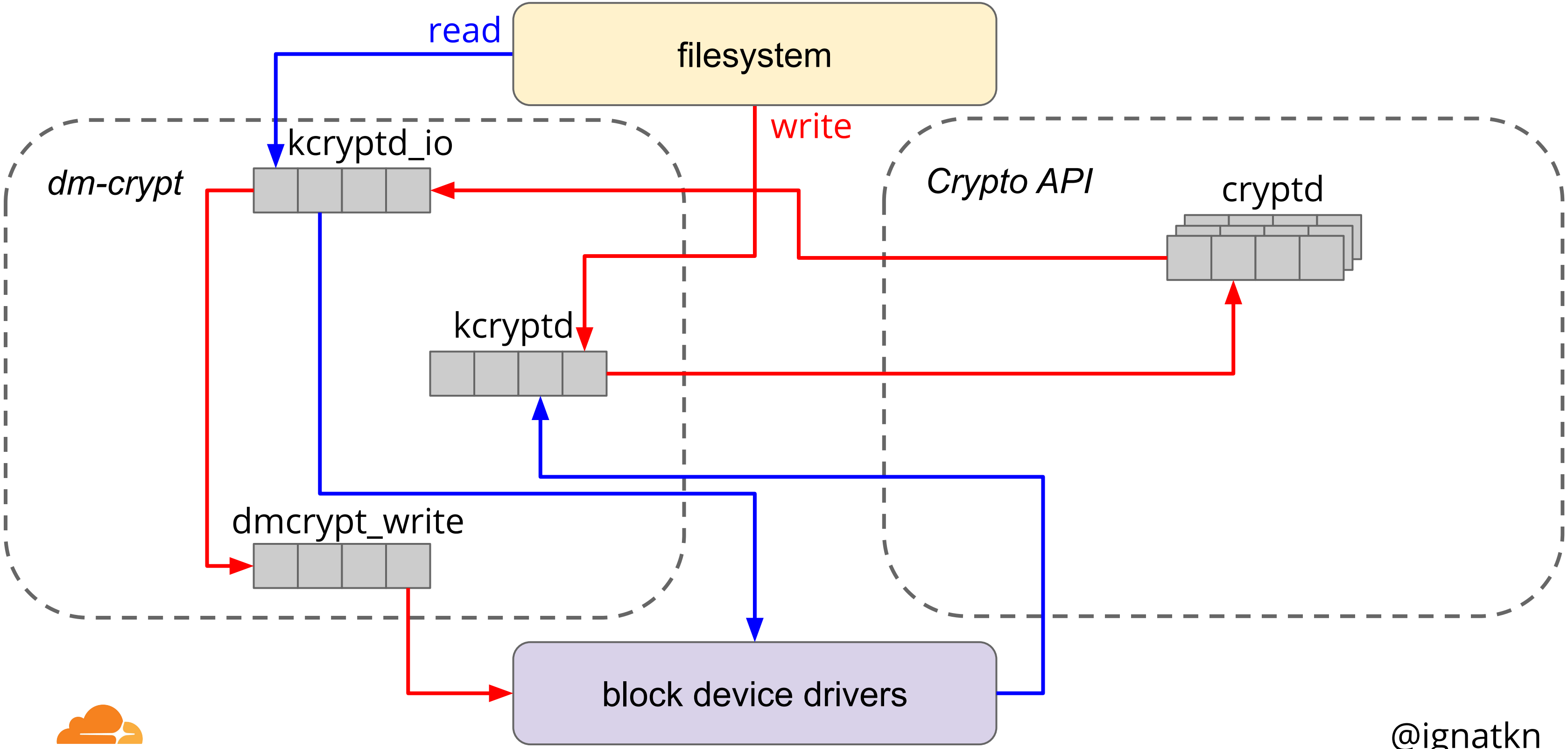

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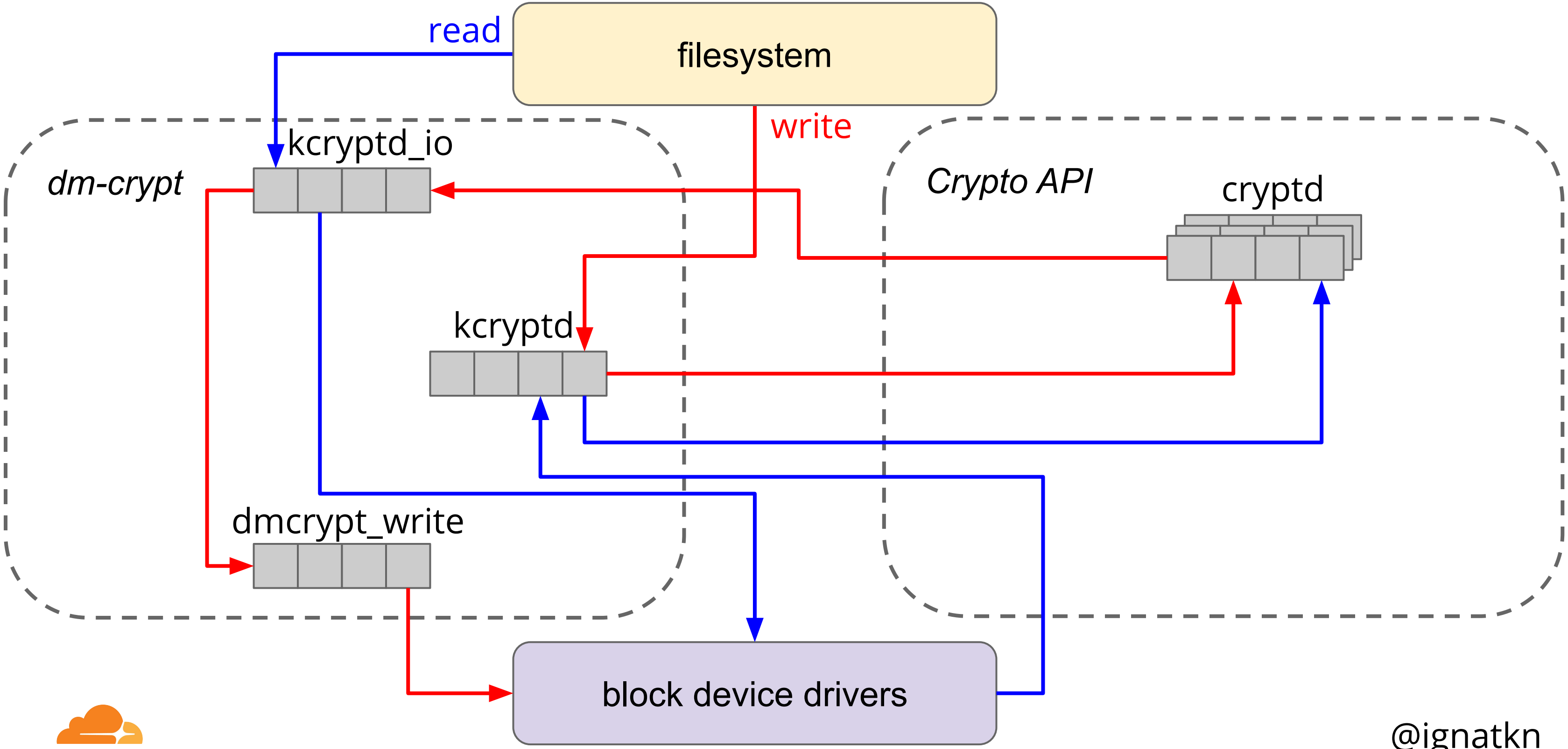

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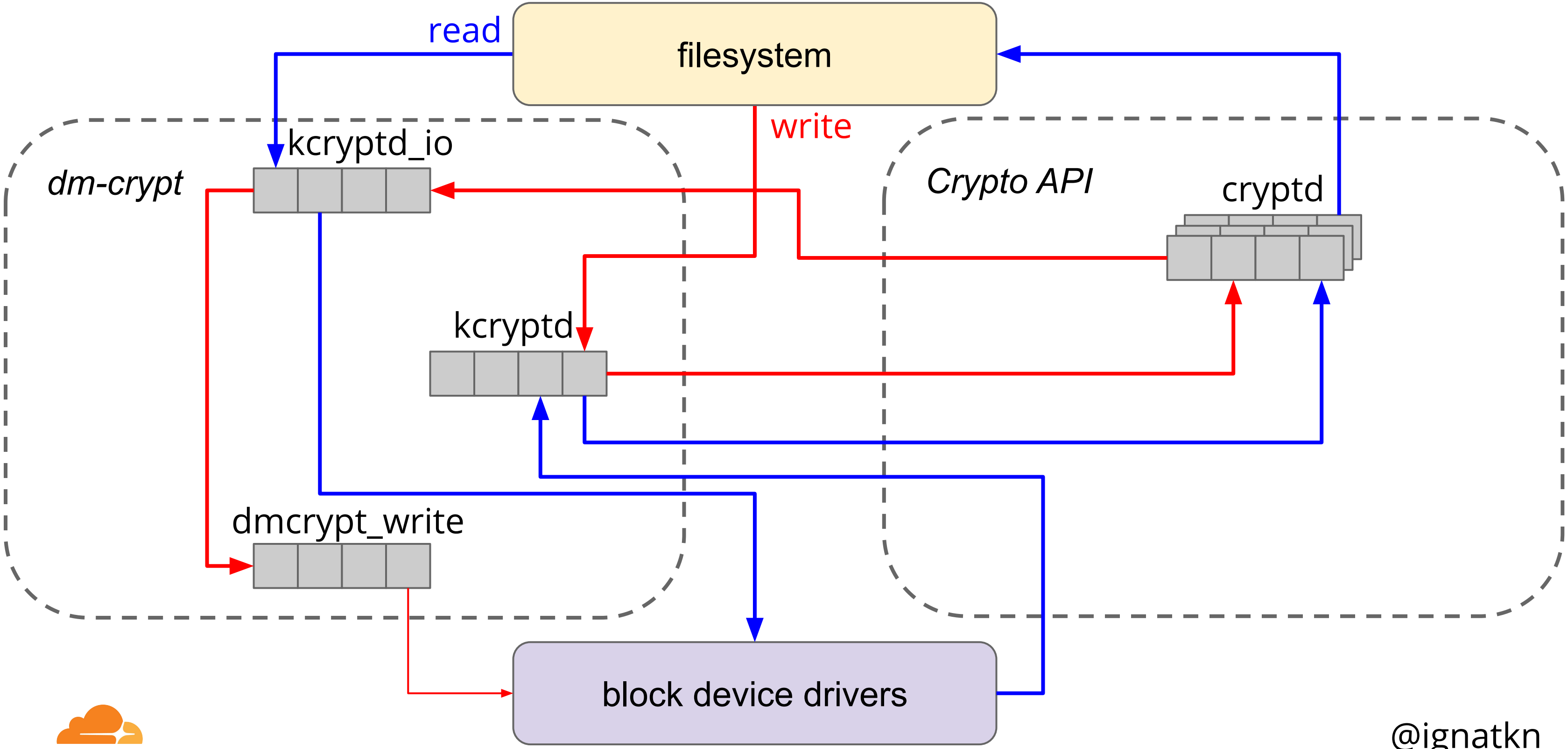

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queues vs latency

“A significant amount of tail latency is due to queueing effects”

https://www.usenix.org/conference/srecon19asia/presentation/plenz

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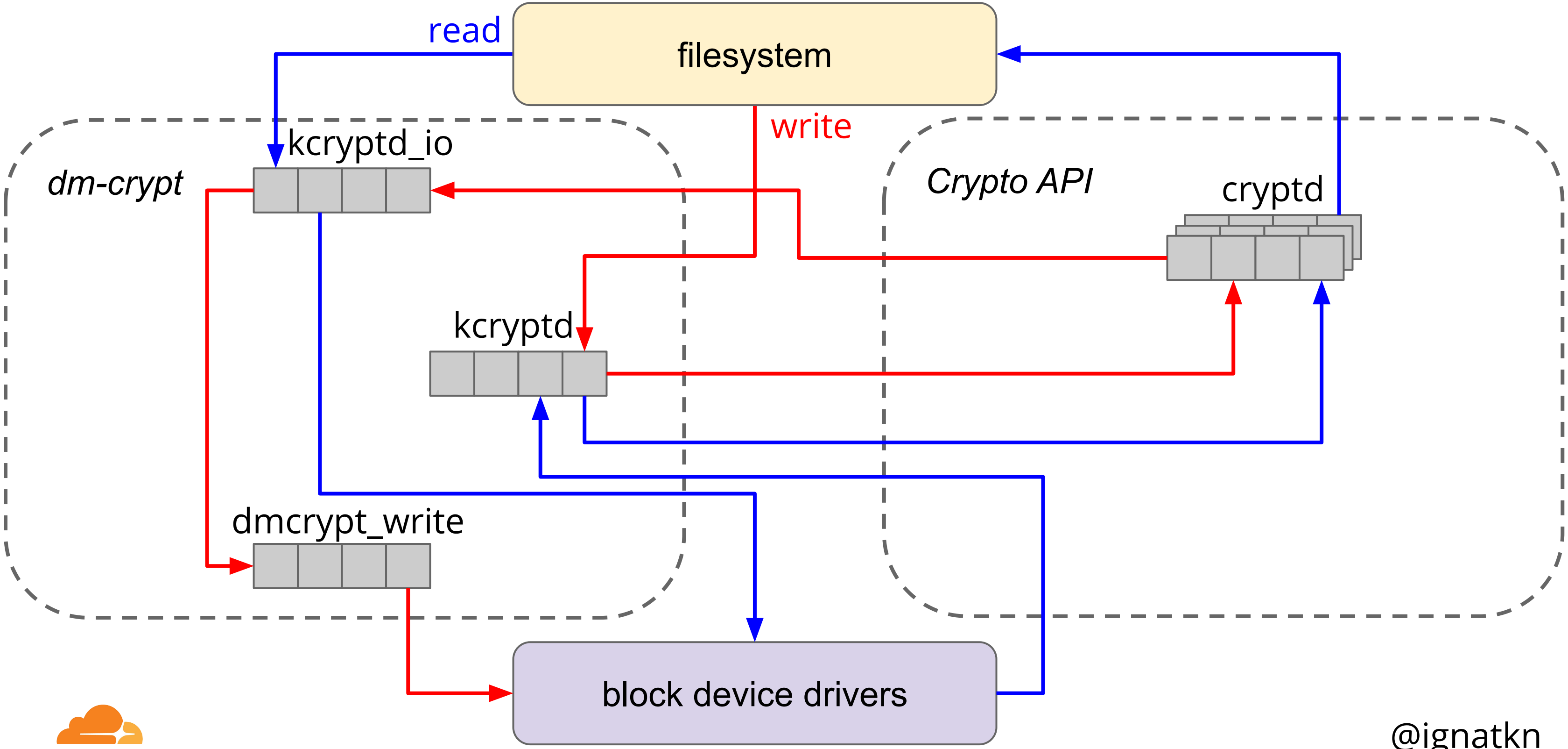

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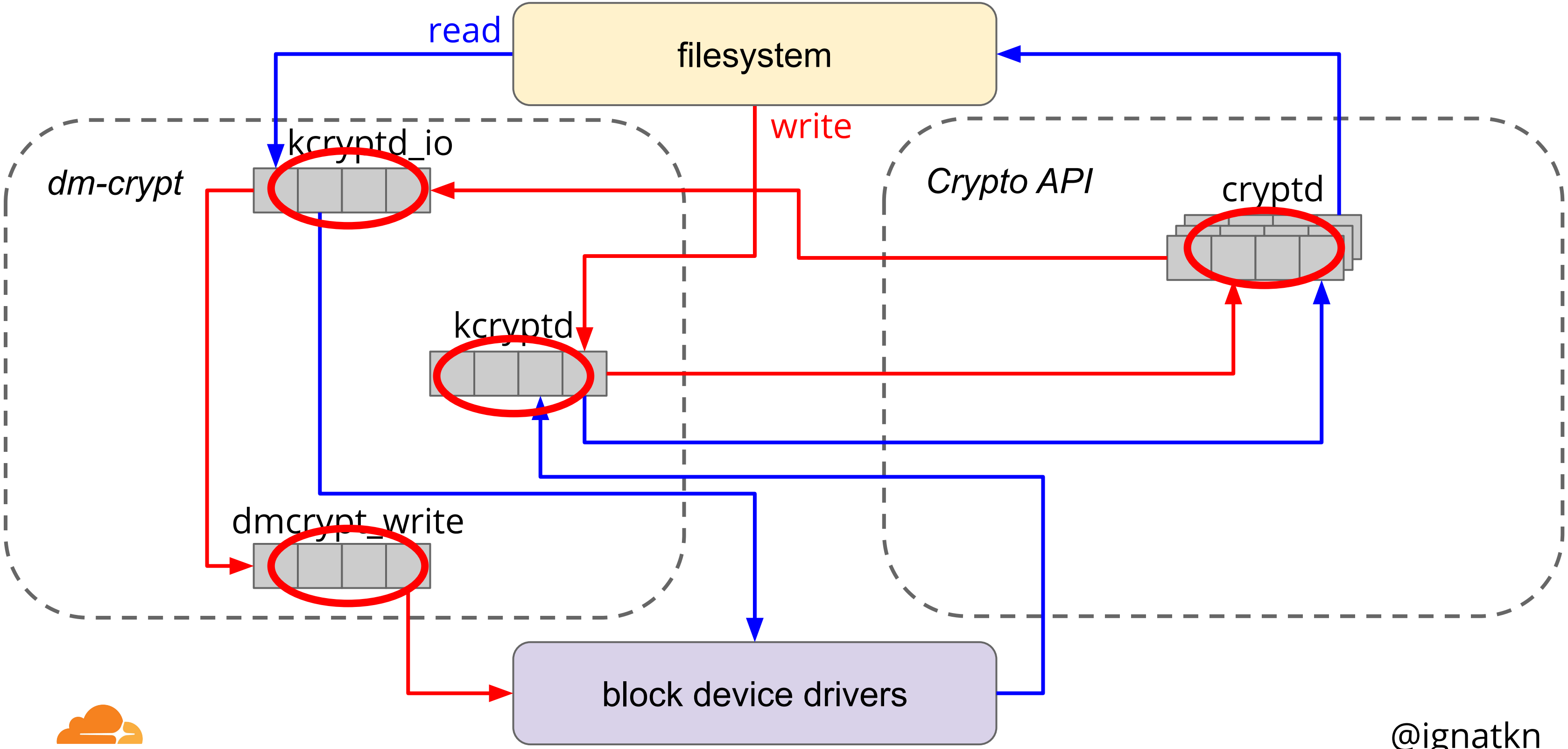

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- offload writes to thread and IO sorting (2015)
  - for spinning disks, but “may improve SSDs”
  - mentions CFQ scheduler, which is deprecated
- commits to optionally revert some queuing
  - “`same_cpu_crypt`” and “`submit_from_crypt_cpus`” option flags

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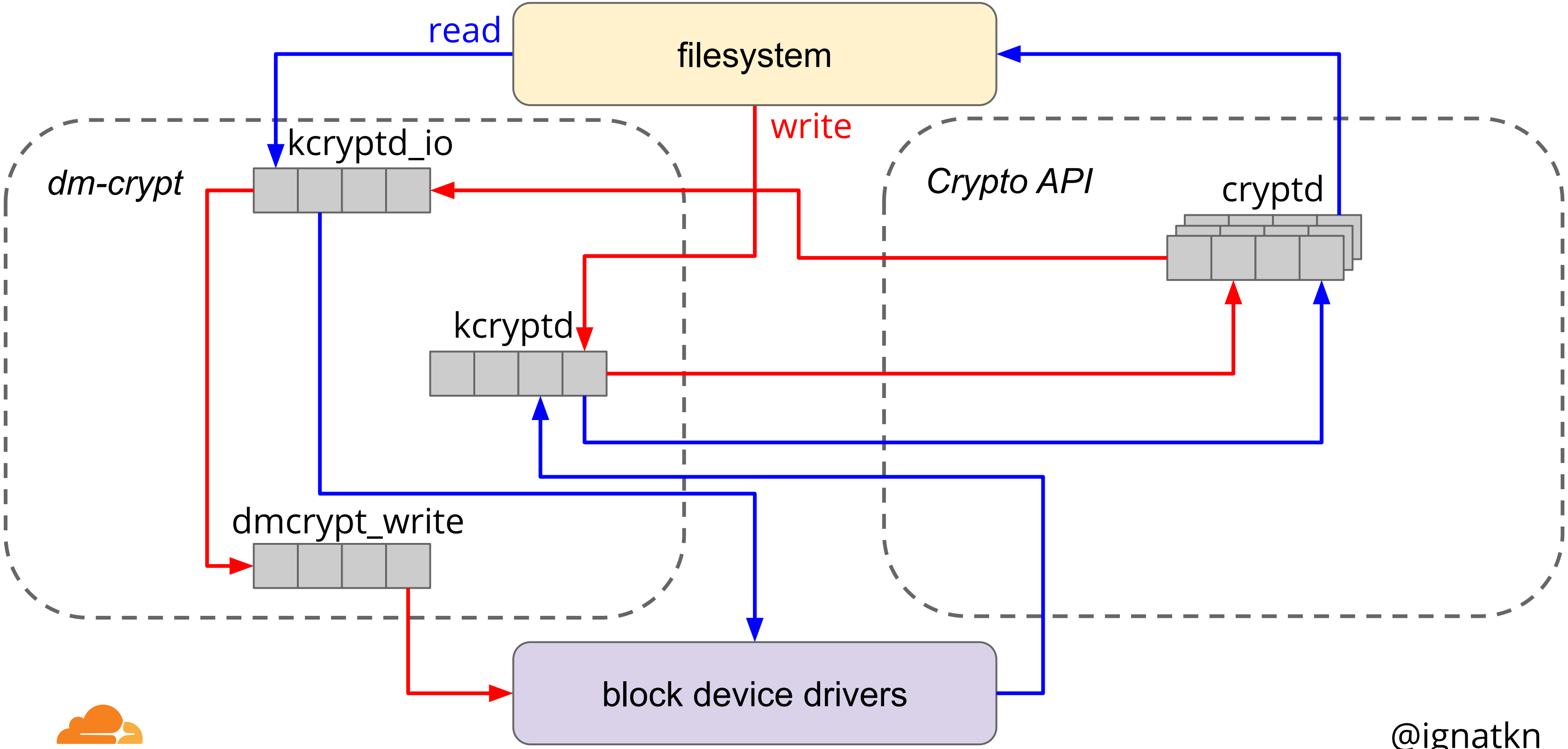
- most code was added with spinning disks in mind
  - disk IO latency >> scheduling latency
- sorting BIOs in dm-crypt probably violates “do one thing and do it well” Unix principle
  - the task for the IO scheduler
- `kcryptd` may be redundant as modern Linux Crypto API is asynchronous by itself
  - remove offloading the offload

dm-crypt: cleanup

dm-crypt: life of an encrypted BIO request



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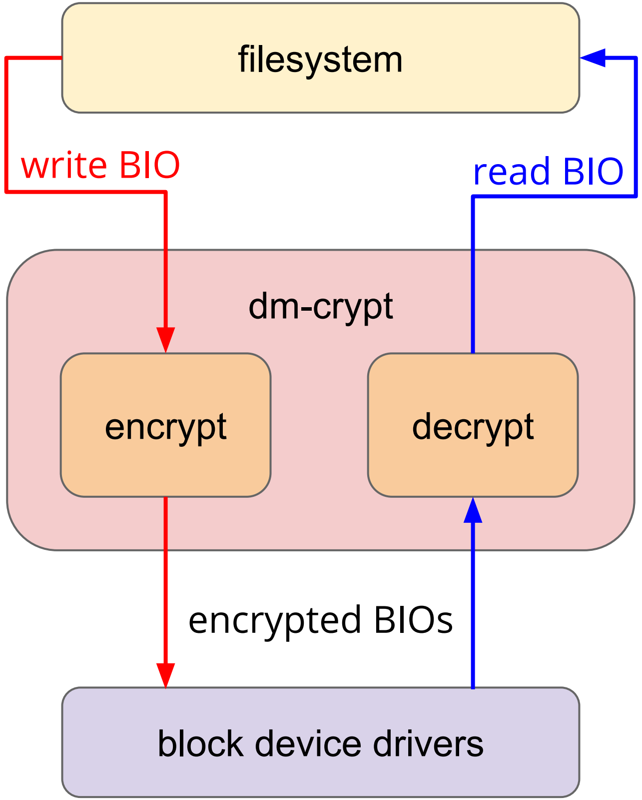
dm-crypt (synchronous)



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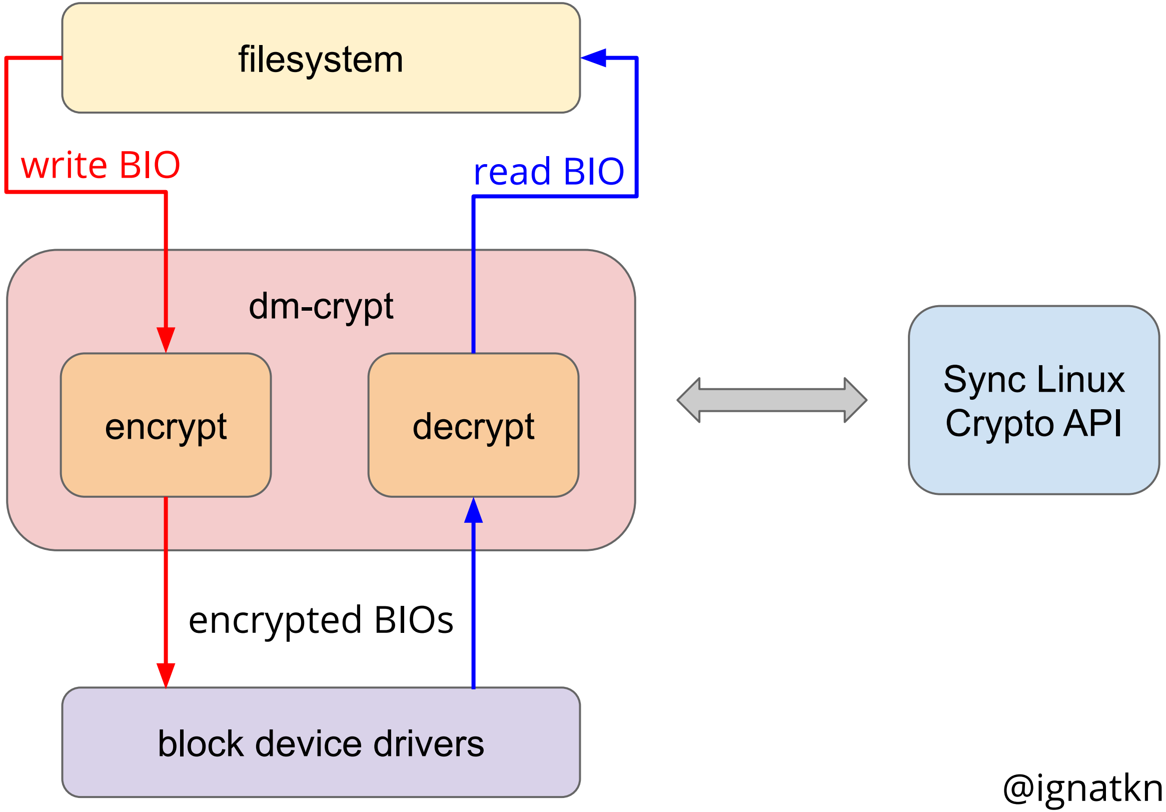

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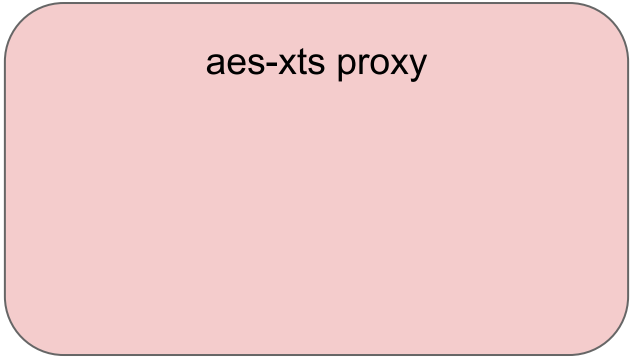
- xtsproxy: a dedicated synchronous aes-xts module

xtsproxy crypto API module



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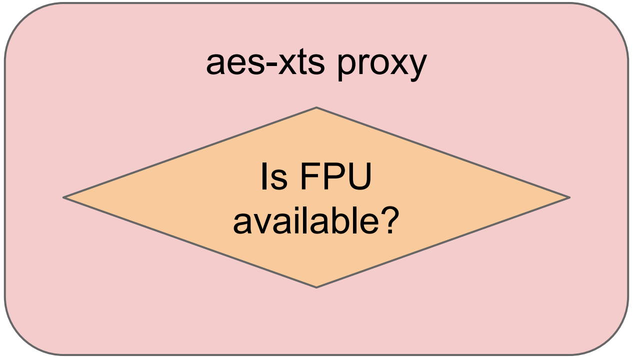

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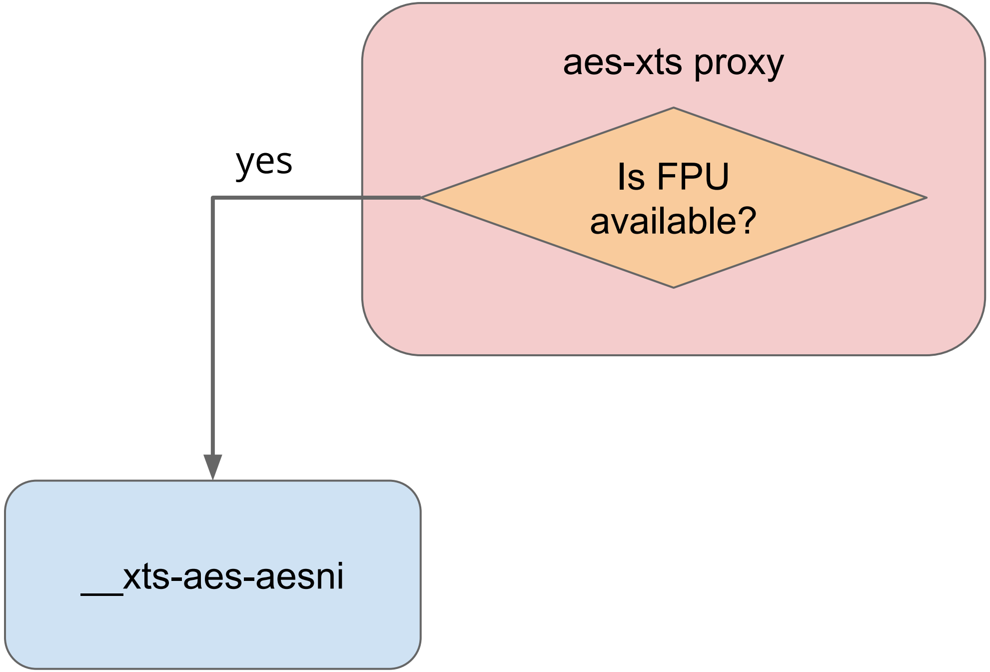

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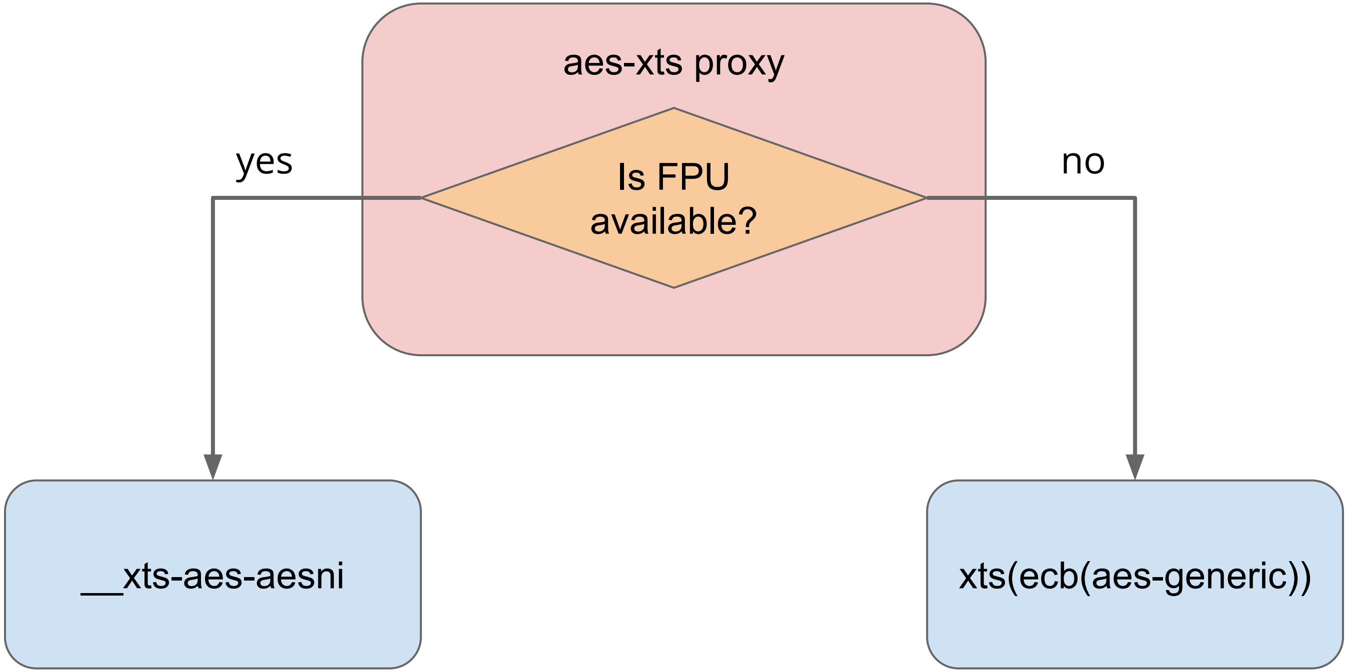

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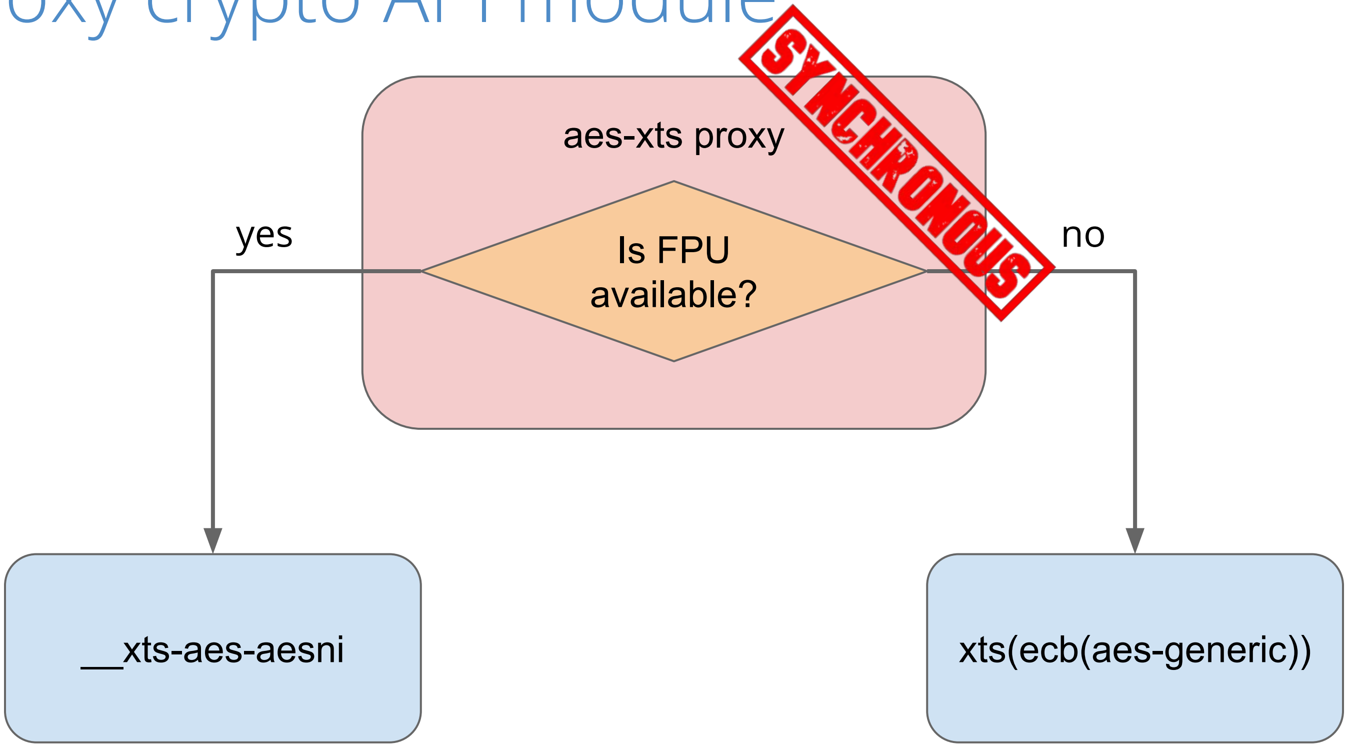

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Test setup: sequential IO

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$ sudo fio --filename=/dev/mapper/secure
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$ sudo modprobe xtsproxy

$ sudo dmsetup table secure --showkeys | sed
's/aes-xts-plain64/capi:xts-aes-xtsproxy-plain64/' |
sed 's/$/ 1 force_inline/' | sudo dmsetup reload
secure
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$ sudo dmsetup suspend secure && sudo dmsetup resume
secure
```

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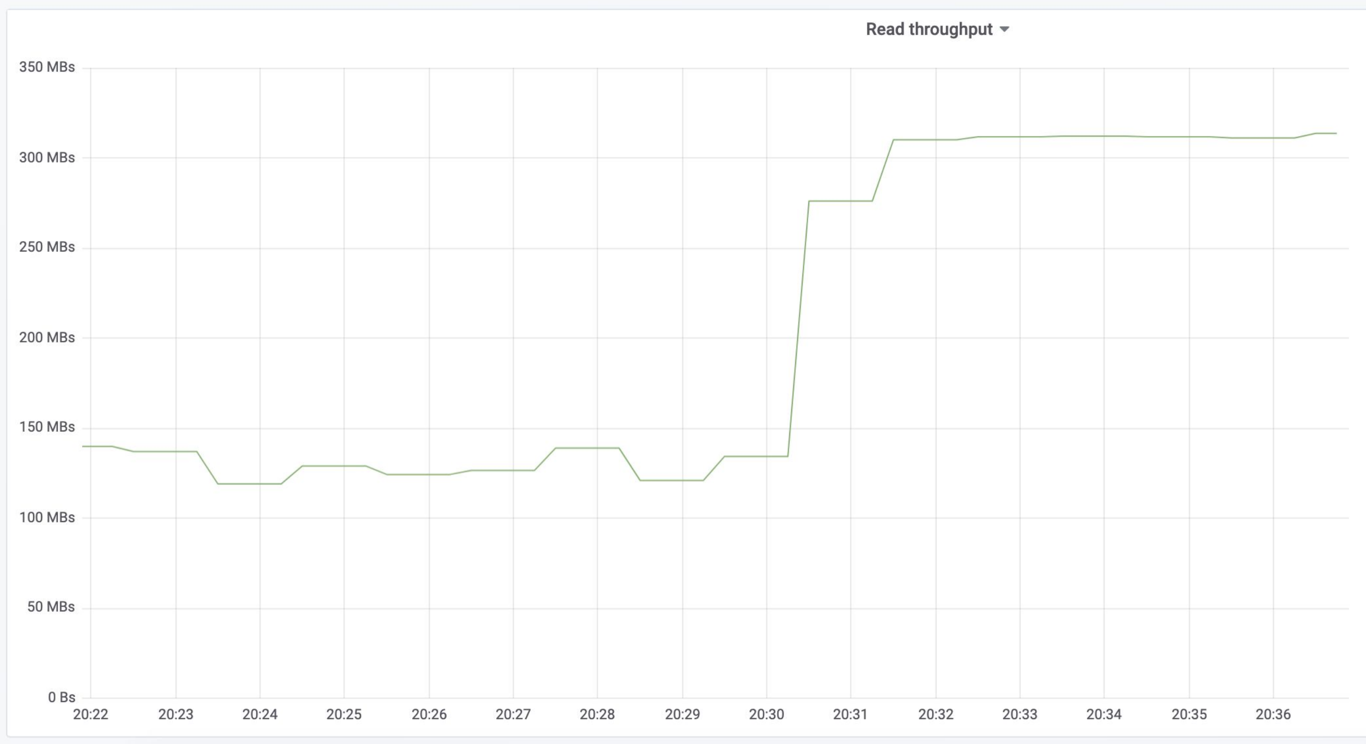
ramdisk: read throughput



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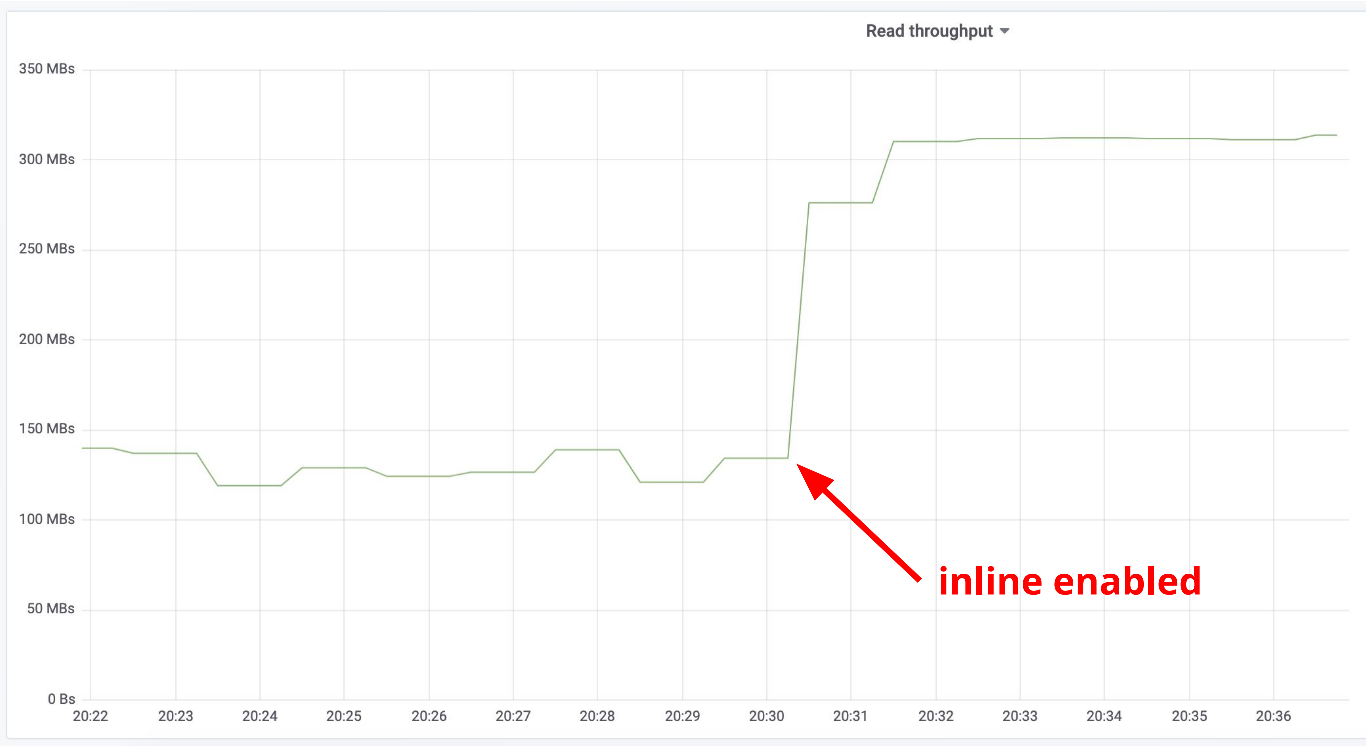

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ramdisk: write throughput

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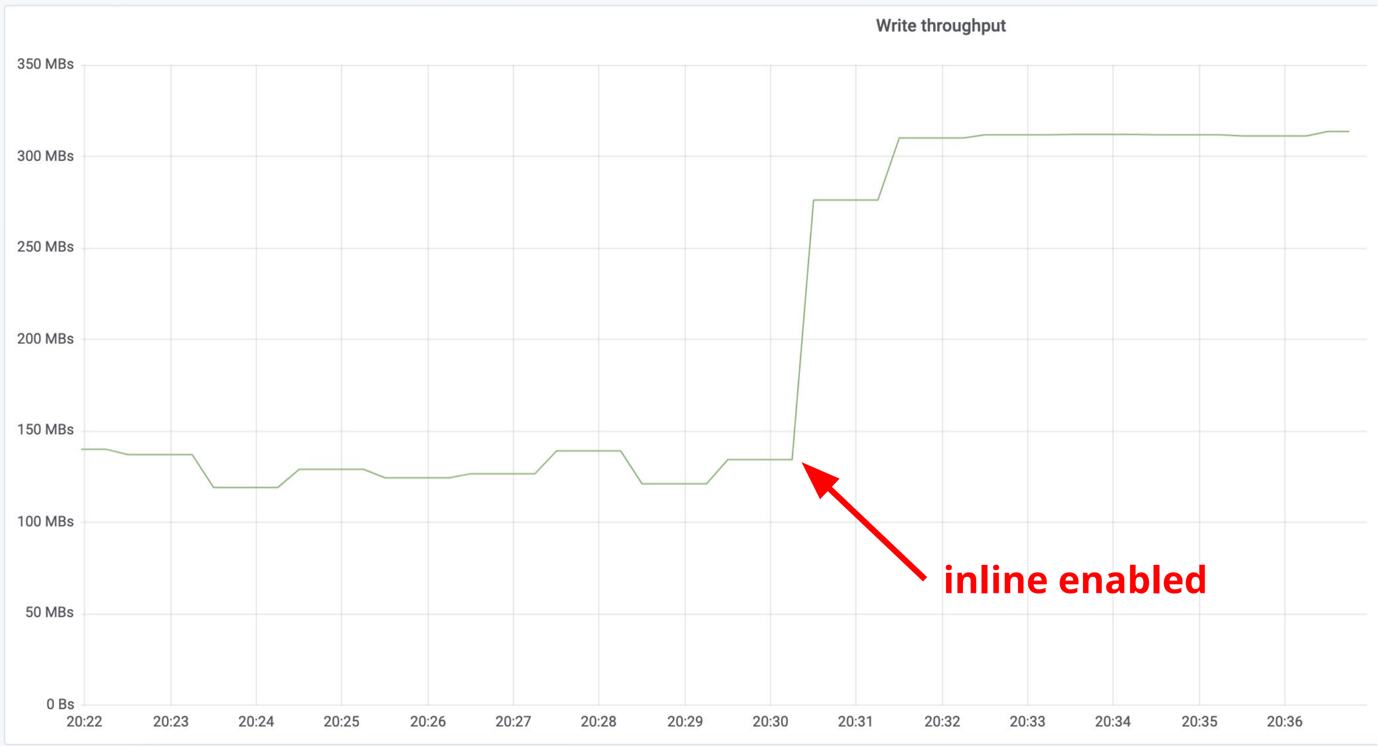

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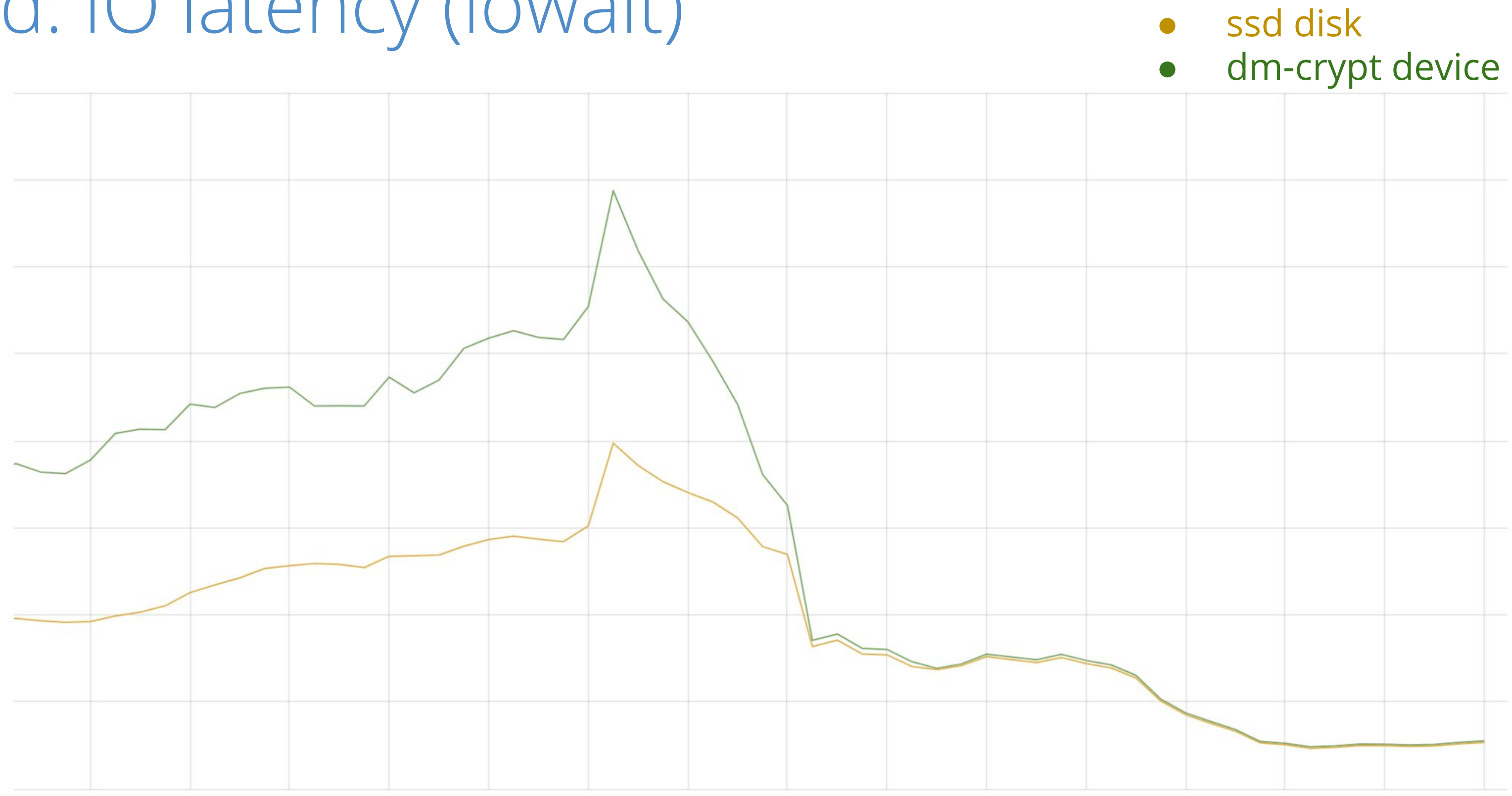
ssd: IO latency (iowait)



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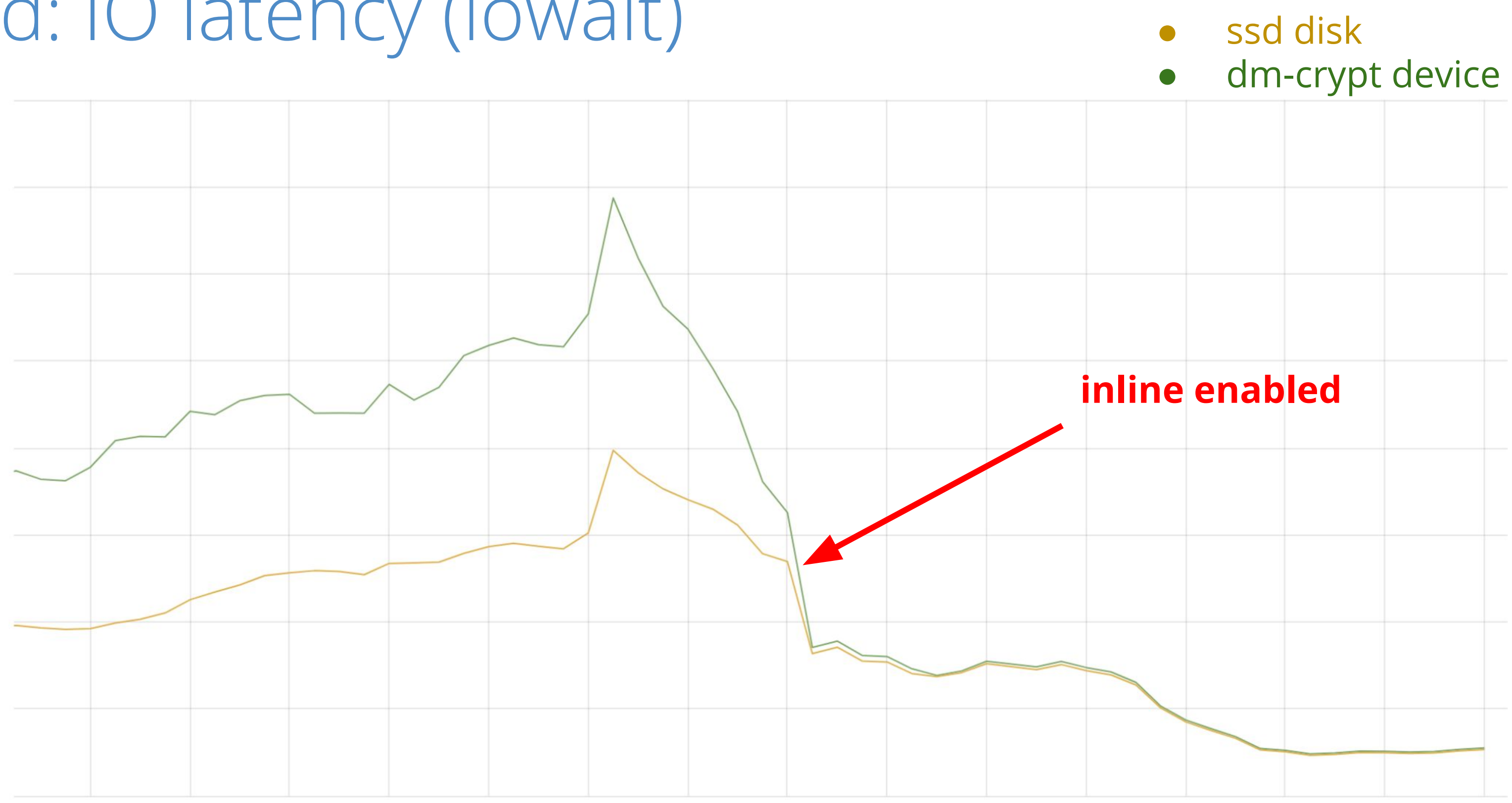

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  - fully compatible with stock Linux dm-crypt
  - can be enabled/disabled in runtime without service disruption
- modern crypto is fast and cheap
  - performance degradation is likely elsewhere
- extra queuing may be harmful on modern low latency storage

Caveats and future work

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  - >2MB block size shows worse performance
- the whole setup assumes hardware-accelerated crypto
  - xtsproxy supports x86 only
- your mileage may vary
  - always measure and compare before deployment
  - let us know the results

Links

- https://gitlab.com/cryptsetup/cryptsetup
- http://man7.org/linux/man-pages/man8/dmsetup.8.html
- https://github.com/cloudflare/linux

Questions?